Consortium for
Electricity
Reliability
Technology
Solutions

Reliability Adequacy Tool for VAR Management

FUNCTIONAL AND DESIGN SPECIFICATION
For the
CALIFORNIA INDEPENDENT SYSTEM OPERATOR (CAISO)
PROTOTYPE

Draft - Version 1.0

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Background

Industry restructuring has driven the California Independent System Operator (CAISO) to manage a larger, more complicated, and dynamic grid. However, the existing support systems and tools used to manage the grid are based on the deterministic procedures of traditional energy management system (EMS) data and applications. To address the shortcomings of the current generation of tools, CERTS developed a vision for integrated, real time reliability adequacy tools.

The Reliability Adequacy Tool for VAR Management (prototype) is a component of CERTS' vision. It has been developed and prototyped for the CAISO operators so they can ensure compliance with the new WSCC grid reliability standards.

Value to CAISO and Industry

Todays operators lack the singular control of reliability and efficiency processes as they did in the past. In addition, there are many new players interacting with the network, each with differing levels of understanding and operating experience. This situation demands new tools to identify adequacy of suppliers (generation), distribution (transmission), and retail (distribution). To be efficient and effective, operators must monitor current performance, historical performance, and most important predict near term behavior. The VAR Management application delivers these capabilities to the system operator.

Real Time VAR Management

The Reliability Adequacy Tool for VAR Management delivered to CAISO contains four main functions: performance monitoring, tracking, probabilistic predictions and simulations.

- Performance Monitoring – monitor CAISO's compliance with National or WSCC Reliability standards for adequate voltages and reactive reserve margins.
- Tracking – The program time tags and tracks substation bus voltages, reactive reserves and the CAISO's voltage performance.
- Probabilistic Prediction – The program uses Powel's Network Calculator (NetBas) engine and the Near Real Time Forecast (NRTF) algorithm. Using real time data these programs provide short-term probabilistic predictions for load, reactive reserves needs, voltages sensitivities and distances before voltage collapse.
- Simulation – This function provides the CAISO Security Coordinators with preventive security assessment and self-training capabilities utilizing interactive simulations with historical and forecast data.

The Application evaluates CAISO's compliance with NERC and WSCC reliability standards for voltage stability at key substations. The performance parameters for each of the four major functions above are based on the NERC and WSCC metrics for reliability standards and voltage stability.

- NERC Policies 2 and 10 which address transmission operations and ancillary services
- WSCC and the following policies and guidelines:
    a) "Voltage Stability Criteria, Undervoltage Load Shedding Strategy and Reactive Power Reserve Monitoring Methodology",
    b) "Dynamic versus Static VAR Sources",
    c) "Undervoltage Load Shedding Guidelines".

The network calculation determines the voltages, voltage sensitivities and distances before voltage collapse at key buses. It also calculates active and reactive flows through the network for current conditions and for near real time load forecast.

The tool for VAR management also includes an enhanced visualization subsystem that aids the Security Coordinator's identification and analysis of voltage stability problems. The visualization methods and techniques are better suited to the new operational challenges raised by the operation of bigger and more complex control areas under competitive market pressures. A key question that the dispatcher can now answer is *"how much can I demand from the system before it causes a blackout?"*

System Hardware

The Reliability Adequacy Tool for VAR Management utilizes standard Intel/Windows based workstations interconnected using Ethernet. This straightforward hardware configuration facilitates integration to the CAISO's current and future information systems.

The applications are loosely integrated with the CAISO's PI information system for data extraction, and this integration can be enhanced as the PI data expands its repository of measured values.

Deliverables

Functional Specification	October 20, 2000
Factory Test completed	December 22, 2000
Field Test completed	January 31,2001
Final Delivery	February 2, 2001

1 INTRODUCTION

The Consortium for Electric Reliability Technology Solutions (CERTS) has been formed to perform research, develop, and commercialize new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structure. The members of CERTS include former Edison Technology Solutions (ETS), Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), the Power Systems Engineering Research Consortium (PSERC), Pacific Northwest National Lab (PNNL) and Sandia National Laboratories (SNL). Southern California Edison (SCE) acts as a CERTS Research Provider.

Industry restructuring has driven the California Independent System Operator (CAISO) to manage a more complicated, dynamic and larger grid. However, the CAISO's support systems and tools used to manage the grid are based on old deterministic procedures and traditional energy management system (EMS) data and applications. New real time integrated reliability adequacy tools are needed that can provide the following:

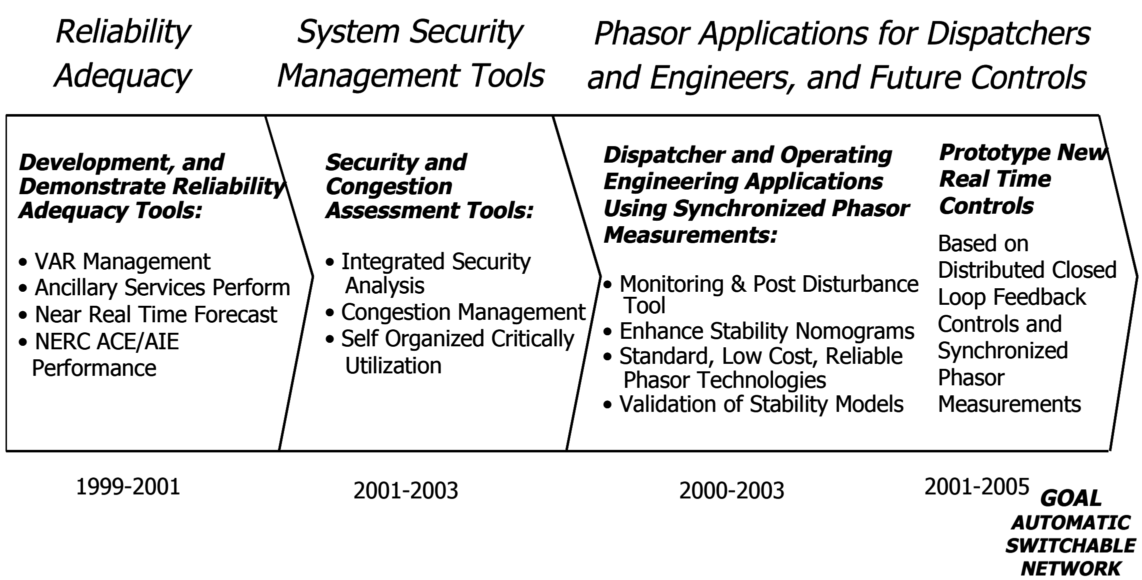
- Grid security assessment from a probabilistic approach.
- Information management systems to convert real time operating data into meaningful operational information.
- Present real time and security assessment data for larger control areas on appropriate visual components and perspectives that allow for effective visual monitoring analysis and assessment of power system events and its potential causes.
- Capability of early preventive warning indications of potential voltage problems (high or low) and reactive resource shortage problems with sufficient time to take the necessary corrective actions that would prevent voltage collapse or equipment damage.
- Capability to monitor adequacy performance for system and suppliers reactive resources.
- Capability for simulations using historical and predictive data for security assessment and self-training purposes.

CERTS is in the process of developing and prototyping a series of modular but integrated computer based reliability adequacy tools that will help CAISO to comply with the WSCC grid reliability standards. A part of the integrated reliability adequacy series, the Real Time VAR Management application is being prototyped for CAISO. The Real Time VAR Management application is designed to measure performance and track system voltage and reactive reserves adequacy, in addition to providing predictive reliability conditions based on near real time forecasts.

1.1 VAR Monitoring Functionality

Figure 1 shows CERTS incremental approach for developing, prototyping and demonstrating adequacy applications with an ultimate goal to evolve and operate towards automatic switchable power networks. The first phase of the application series was to develop and demonstrate PC-based workstations for VAR Management and Ancillary Services application prototypes for dispatchers, see left side from Figure 1. The second phase is to develop and demonstrate a security monitoring applications, designed for dispatchers and operating engineers, using Synchronized Phasor Measurements (SPM), see center from Figure 1.

Figure 1 – CERTS Incremental Roadmap Towards an Automatic Switchable Network



The four main functions of the Real Time VAR Management reliability adequacy application are performance monitoring, tracking, probabilistic predictions and simulations. The performance parameters for each of the four major functions are based upon NERC and WSCC metrics for reliability standards and voltage stability.

- Performance Monitoring – The program assists the Security Coordinator by monitoring CAISO's compliance with National or WSCC Reliability standards to maintain adequate voltages and reactive reserve margins.
- Tracking – The program time tags and track data used to monitor substation bus voltages, reactive reserves and the CAISO's voltage performance.
- Probabilistic Prediction – The program utilizes Powel's Network Calculator (NetBas) network analysis engine and the Near Real Time Forecast (NRTF) algorithm. Using the most recent real time data the analytical engines provide short-term probabilistic predictions for load, reactive reserves needs, voltages sensitivities and distances before voltage collapse. The visual components of historic and actual behavior and predictions of reactive power are presented using geographical and graphical visual analysis system that is designed to enable effective and timely decisions in managing system reliability.
- Simulation – This function provides the CAISO Security Coordinators with preventive security assessment and self-training capabilities utilizing interactive simulations with historical and forecast data.

The functionality of the Real Time VAR Management system is based on a process defined by CERTS for reliability adequacy tools, and on the voltage-reactive reliability standards from two organizations:

- NERC Policies 2 and 10 which address transmission operations and ancillary services
- WSCC and the following policies and guidelines:
    d) "Voltage Stability Criteria, Undervoltage Load Shedding Strategy and Reactive Power Reserve Monitoring Methodology",
    e) "Dynamic versus Static VAR Sources",
    f) "Undervoltage Load Shedding Guidelines".

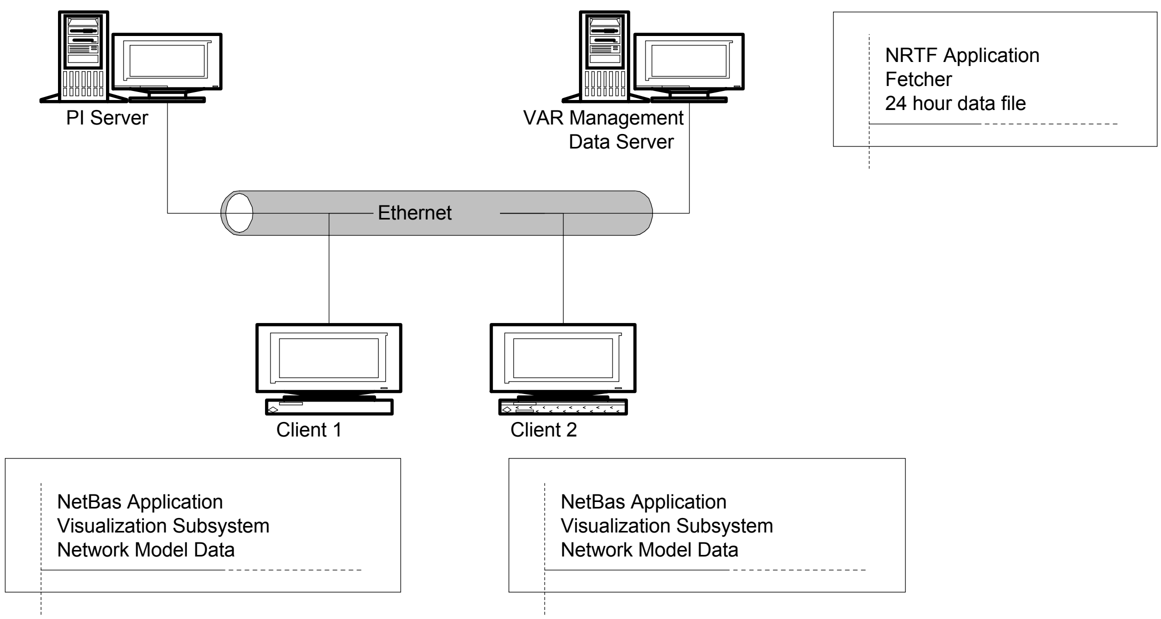
The Real Time VAR Management application can be used to evaluate CAISO's voltage stability compliance with NERC and WSCC reliability standards at key substations. The network calculation determines the voltages, voltage sensitivities and distances before voltage collapse at key buses. It also calculates active and reactive flows through the network for current conditions and for near real time forecast load.

The Real Time VAR Management system also includes a new information visualization subsystem to assist the Security Coordinator's identification and analysis of voltage stability problems. The visualization methods and techniques are better suited to the new operational challenges raised by competitive markets and the operations of bigger and more complex control areas.

1.2 System Hardware and Software Overview

Figure 2 shows an overview of the three PC-based computers that make up the hardware infrastructure for the VAR Management. The figure also shows the application software that will reside in each computer.

Figure 2 – Hardware and Application Software Overview



1.3 VAR Management Utilization

Security Coordinators can use VAR Management application to identify:

- Voltage abnormal events
- The relationship with reactive-reserve conditions
- The voltage sensitivities at critical bosses
- Loading distances before voltage collapse

Figure 3 shows the six recommended sequential summary steps for dispatchers to timely and effectively identify those areas of the network that are closer to violate voltage stability limits.

Step-1 – 2D Voltage Flashing Alarms – Visual component showing specific stations with voltages under predetermined thresholds.

Step-2 – 3D IsoVoltage Patterns – Visual component showing some specific stations as in step-1 but in a graphic 3D display with isovoltage contours included.

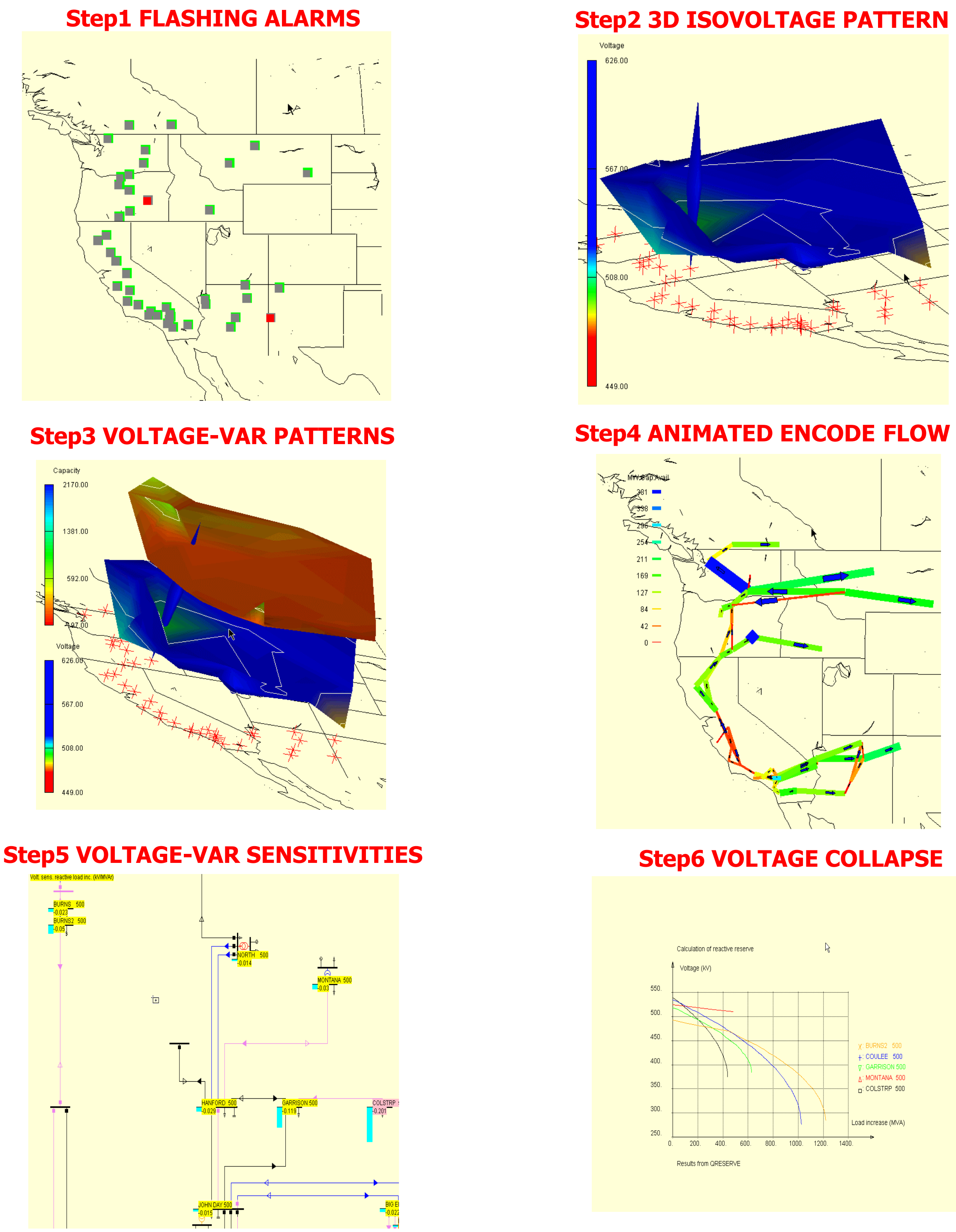
Step-3 – Voltage / VAR Patterns – Visual component that correlates voltage trouble- areas with corresponding reactive reserve patterns.

Step-4 – Animated / Encoded Flows – Visual component showing the power flows with line-capacities and flow direction encoded with line-wide an animated arrows.

Step-5 – Voltage Sensitivities – Visual component with vertical bars in a one-line diagram showing voltages changes to marginal load increase for pre-selected buses.

Step-6 – Voltage Collapse Distances – Visual component showing how much it is possible to load up pre-selected buses before voltage instability occurs.

Figure 3 – VAR Management Utilization Steps for Dispatchers



1.4 Overview of the VAR Management and Specification

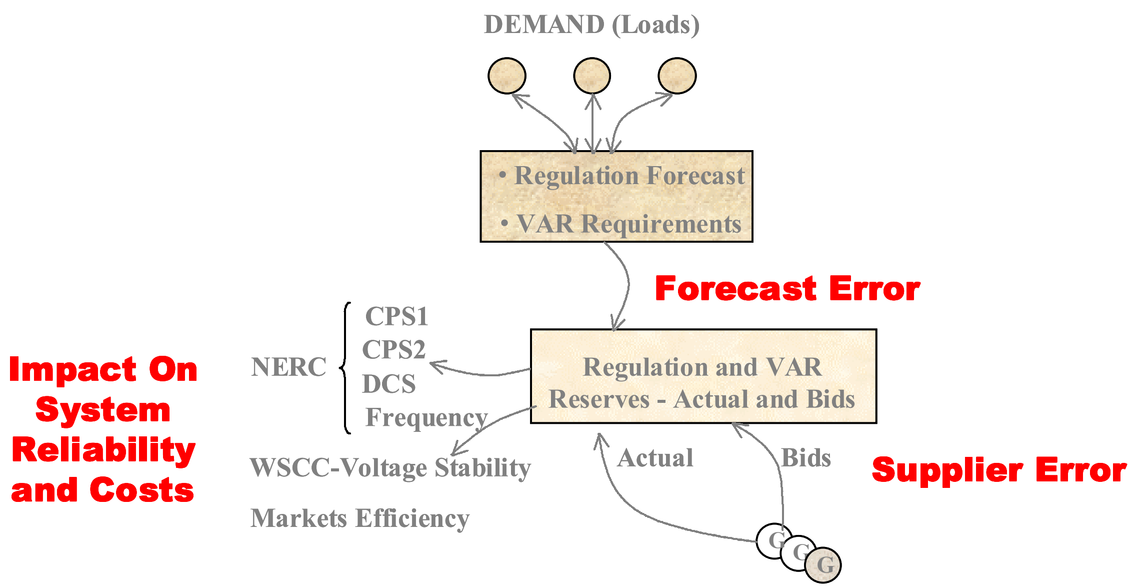
The remaining sections of this specification will cover the following areas - Section 2 describes how operational changes originated from deregulation and how competitive markets require tools to track adequacy of reactive reserves. Section 3 describes the target users for this tool, and Sections 4 and 5 describe the functionality information and visualization elements for VAR Management. Section 6 describes general characteristics of the design for the application.

The Real Time VAR Management system will reside in high-powered PC based workstations, running Windows NT. As shown in Figure 2, the software and hardware, described in this document, have been specifically configured and implemented for this application and is part of the CAISO working prototype.

2 BACKGROUND

Figure 4 shows an overview of the current and potential VAR market and operational processes that were used for the definition of the functional requirements for VAR Management application.

Figure 4 –Demand (Loads)



The process starts, as shown in Figure 4, with CAISO preparing their forecast of VAR requirements, and the supply bidders using that forecast to present their bids. Any errors in the forecast or deviation between suppliers' bid and actuals will impact voltage stability and consequently could result in CAISO's non-compliance with WSCC voltage stability standards.

It should be noted that VAR suppliers in the above generic process can take different roles depending on the voltage and reactive reserve characteristics of particular regions. Today the CAISO requires Reactive Must Run (RMR) generation to satisfy region voltage requirements. In the future, the ancillary services market will enable the participation of CAISO's contract suppliers and other suppliers with capacitors in the transmission system.

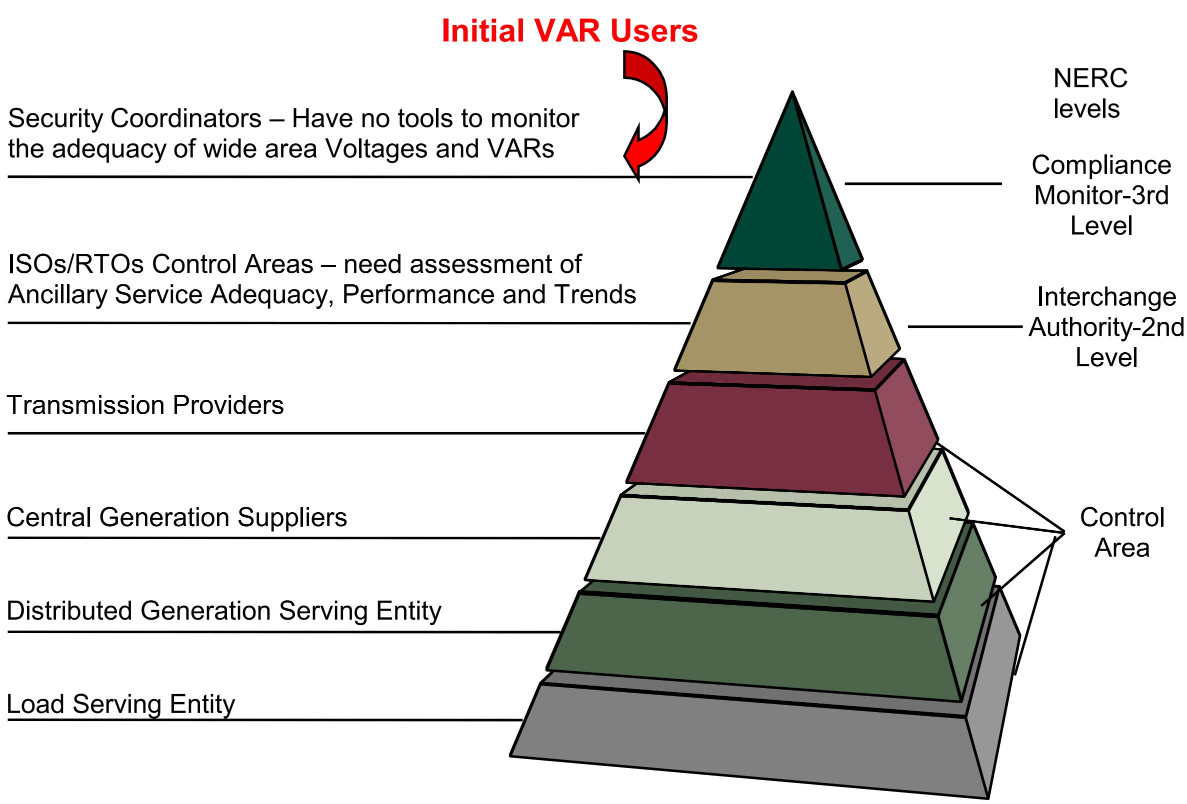
3 TARGET USERS, THE RELIABILITY STANDARDS AND METRICS

North American utilities formed the North American Electric Reliability Council (NERC) in 1968 to coordinate, promote, and communicate the reliability of their generation and transmission systems. NERC helps utilities work together to maintain and improve system reliability by:

- Developing and maintaining Policies and Standards, for the reliable operation and planning of the electric interconnections in North America.
- Measuring performance of systems for compliance with the reliability Policies and Standards.
- Ensuring compliance with the reliability Policies and Standards through well-defined, effective, and timely procedures.

Industry stakeholders are recognizing new reliability jurisdictions and real time controls within emergent market environments that follow a hierarchical structure with new jurisdictional levels that did not exist before. Figure 5 shows the current hierarchical levels for power system reliability and control management. The figure also shows the corresponding reliability levels identified by NERC and whose reliability roles and responsibilities are currently being defined.

Figure 5 – Reliability and Control Hierarchy



The functional requirements for new reliability adequacy operational tools and real time control systems will depend on the operational level and approach that is being addressed, the traditional central approach or new distributed approaches. The functionality identified and described on this specification has been oriented towards the distributed control and monitoring environments, with the operating authority following the hierarchical control levels shown in Figure 6.

Figure 6 – Shows NERC roles and responsibilities of the top three operating entities shown in Figure 5 and who have oversight for the necessary reliability services. In Figure 6, the shadowed area corresponds to some of the reliability services that CERTS is addressing with the reliability adequacy tools currently under development.

Figure 6 – Reliability Hierarchy / Entity Responsibility

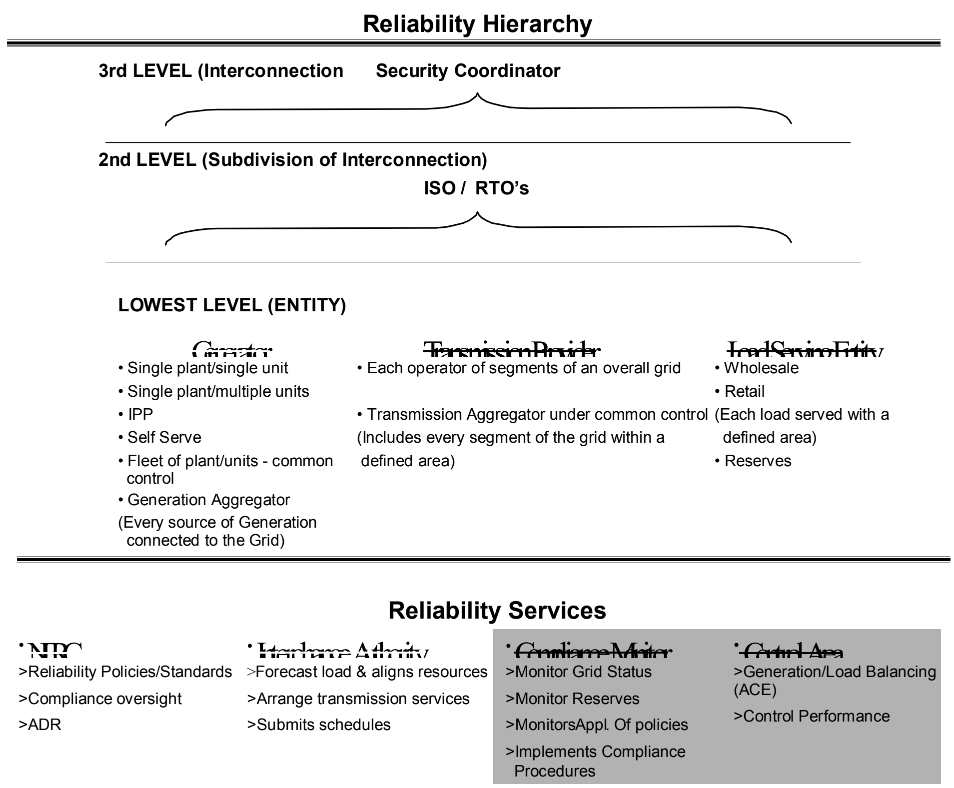
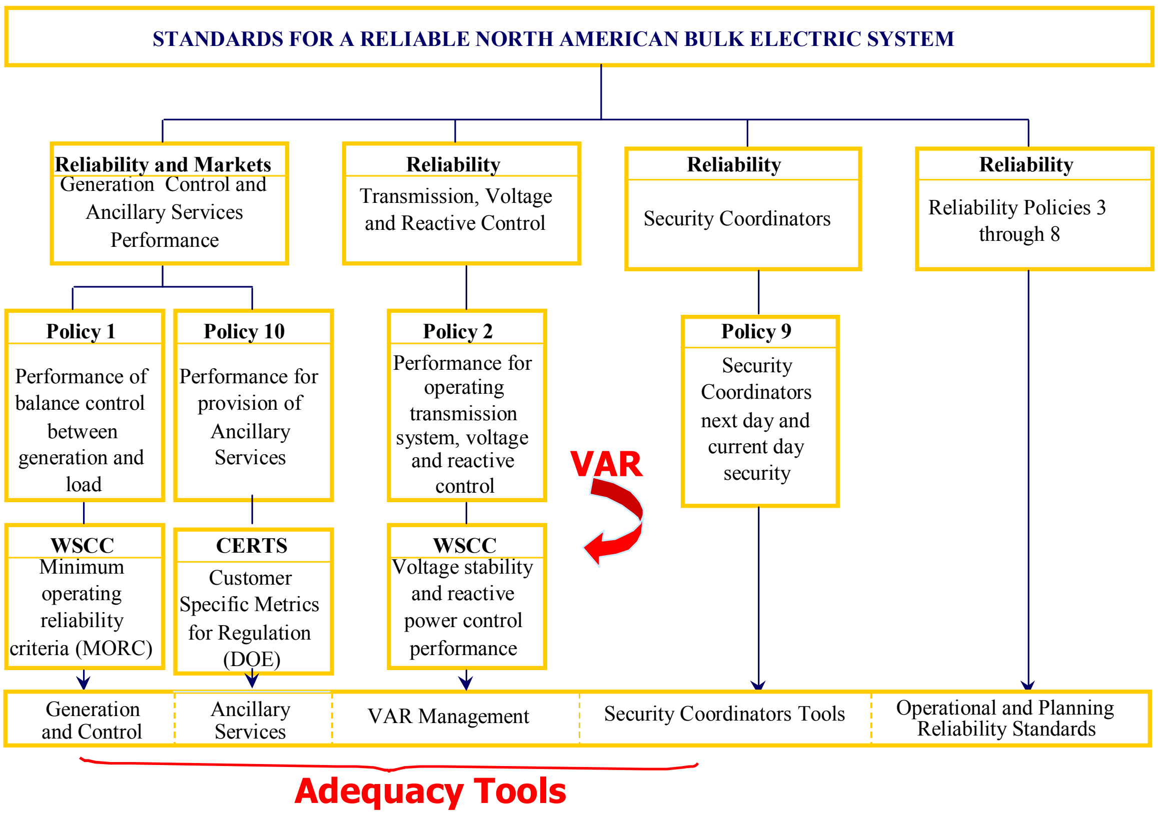


Figure 7 below is an overview of NERC's Policies and Standards with specific details on the interrelationships and performance parameters for Policies 1, 2, 9 and 10. CERTS is focused on these four NERC Policies and has identified the need for reliability adequacy operational tools (bottom of Figure 4) to assist Operating Authorities in effectively monitoring, tracking performance and anticipating short-term reliability needs. Performance tools for NERC's Policies 1 and 10 as well as the WSCC Minimum Operating Reliability Criteria (MORC) are being addressed with the CERTS Ancillary Services Performance Tracking and Predictive specification. This Real Time VAR Management Reliability Adequacy Specification is addressing NERC's Policies 2, 10, and the WSCC voltage stability guidelines.

It should be noted from Figures 5, 6 and 7 that independent of the restructuring approach and business infrastructures implemented in different areas of the nation, Operating Authorities such as ISOs, RTOs, Utilities, etc. will still be responsible for their control area reliability, and consequently they will need new real time operational tools for reliably managing the grid.

Figure 7 – Standards for a Reliable North American Bulk Electric System



3.1 Generation Control and VAR Management – A Market Perspective

California's ISO has established hourly ancillary services markets (reactive reserves market could be added in the near future) for the purpose of ensuring reliability and creating competition among potential suppliers, thus enhancing market efficiency.

In the restructured marketplace, by design, generation operators (Suppliers) will be free to make their own decisions about how much VARs to generate in any given hour, subject only to the incentives and penalties embodied in market prices and in contractual relationships.

3.2 Voltage Control and Real Time VAR Management – A System Reliability Perspective

As shown in Figure 7, Security Coordinators and Control Area Operators are responsible for ensuring system reliability through the compliance of standards established by NERC and WSCC. On November 1996 the WSCC Technical Studies Subcommittee (TSS) formed the Reactive Power Reserve Work Group (RRWG) to address reactive power margin issues, as a response to two major disturbances that occurred within the WSCC interconnected region. This specification incorporates RRWG's specific recommendations for reactive power margins and voltage stability criteria performance, and general recommendations from NERC's Policy 10, as described in Table 2, in section 4.2**.**

Reactive Reserves fall mainly under transmission providers or control areas voltage support requirements and must be available to mitigate the impacts of likely contingencies. Table 1 shows the WSCC voltage stability criteria (minimum required margins for each member system) applied according to the type of disturbance and performance level. These criteria will be used as part of the metrics and calculations for the VAR Management application.

The need for measurable standards are driven by industry restructuring, namely:

- Industry competition that precludes the reliability councils from relying solely on voluntary compliance and peer pressure to maintain the current level of reliability.
- Divestiture of generation assets resulting in separation of generation resources from traditional reliability bodies, such as Control Areas;
- Separation of generation and transmission functions within previously integrated utilities requiring new protocols to re-integrate the supply and deployment of reliability services; and
- Development of procedures and protocols within emerging regional market structures.

These standards are necessary to ensure unbundled reliability services to continue to be provided under a range of competitive market structures and conditions.

One reliability objective of the regional interconnected grid is to maintain system voltages within defined limits. This must be maintained under both normal and emergency conditions. The control area accomplishes this by coordinating the use of reactive resources (generators, transmission reactive resources, and load power factor) and ensuring that there are adequate reactive reserves available. The following are the minimum components of transmission system voltage control:

- Load power factor correction.
- Transmission reactive resources (capacitors, reactors, lightly loaded lines and static VAR compensators).
- Generator interconnection voltage and VAR schedule requirements with the local transmission provider.

- Control Area coordination.
- Reactive power supply and high speed voltage regulators at generation sources.

The Operating Authority must deploy the reactive resources necessary to maintain system voltages within established limits and avoid voltage instability or system collapse. One of the technical elements necessary to ensure a stable system voltage is the Automatic Voltage Regulator (AVR) and reactive production / absorption capability of the grids generating units. The following capabilities from generators (and possibly some loads) are essential to maintaining system voltages within limits under pre- and post-contingency conditions: reactive capacity, reactive energy, dynamic and fast acting responsiveness, and the ability to follow a voltage or VAR schedule.

In addition to the use of generation-based ancillary services, the Operating Authority coordinates the use of static reactive supply devices throughout the system, and may develop and impose reactive criteria on load-serving entities.

Voltage support and reactive power control requires that a Control Area meet the following criteria:

- **Voltage Schedule Coordination.** The Operating Authority shall establish, and update as necessary, voltage schedules at points of integration of reactive power supply from generation sources, to maintain system voltages within established limits and to avoid burdening neighboring systems. The Operating Authority shall communicate to the Supplier the desired voltage or VAR schedule at the point of integration.
- **Reactive Reserves.** The Operating Authority shall acquire, deploy, and continuously maintain adequate reactive reserves from Supplier resources, both leading and lagging, under both steady state and contingency conditions
- **Telemetry.** The Operating Authority shall monitor by telemetry the following data: (1) Transmission voltages, (2) Unit or Supplier resource reactive power output. (3) Unit or Supplier resource Automatic Voltage Regulator (AVR) status for units greater than 100 MW (and smaller units where an identified need exists).
- **NERC/WSCC Planning Standards.** The Operating Authority shall comply with applicable NERC/WSCC Planning Standards. These standards require that generation owners and Operating Authorities plan and test reactive power capability.

Each control area shall monitor its performance on a continuous basis against the established Standards, with the desired goal for the control area to meet or exceed the standard specified in Table-2, Section 4.2.

In the simplest form, the resources to support the system voltage and meet the reactive power requirements are reactive capacity and the ability to raise and lower output or demand in response to control signals or instructions. Generators, controllable loads, or storage devices, capacitors, reactors and static VAR compensators may provide this capacity and maneuverability.

Generator power factor and voltage regulation standards can be a condition of interconnection to satisfy area or local system voltage conditions. Voltage regulating capacity and capabilities that are provided to meet minimum interconnection requirements do not imply that those generators are qualified ancillary service suppliers.

Generators do not provide reactive power supply from generation sources simply because of connection to the transmission system. In order to provide the ancillary service, the resources must be

- Under the direction of Operating Authority for the purpose of controlling system voltage, and
- Providing a service under contractual arrangement with the Operating Authority.

3.3 VAR Management Metrics

Table 1 is CERTS proposed overview of the VAR management metrics required to meet the performance, tracking and prediction requirements in a deregulated environment and adhering to evolving reliability standards. System VAR management metrics are implemented in the Visualization subsystem.

Table 1 – VAR Management Metrics

Time Horizon	CAISO Security Coordinators (WSCC P-V, V-Q Margins)
Performance (Actual)	P/V – Times margin at critical busses was <5% for 1-element outage or <2.5% for 2-element outage. V/Q – Times the margin, at most reactive deficient bus for the worst outage condition and an increase of 5% load beyond the forecasted load, was not adequate.
Tracking (Last 1 to 24 hours)	Equivalent performance horizon
Prediction (Next 15 min – 3 hour)	Margins before voltage collapse for a case with near real time predictive load plus 5%

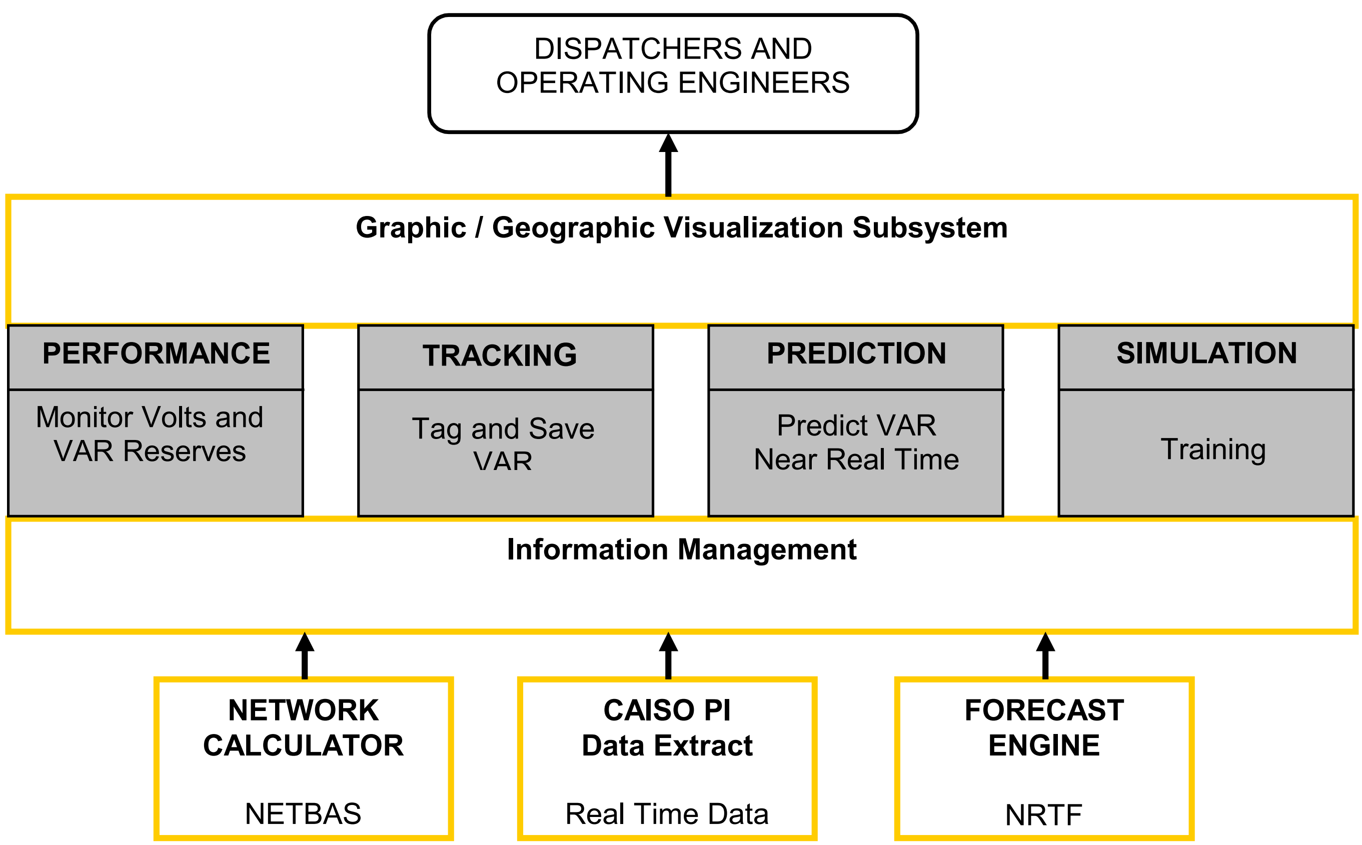
4 REAL TIME VAR MANAGEMENT FUNCTIONAL REQUIREMENTS

The main purpose of the Real Time VAR Management application is to provide actual and predictive voltages, sensitivities, reactive reserve and distance before voltage collapse to CAISO Security Coordinator. In addition, the application has the capability to simulate different scenarios for preventive reliability assessment and self-training capabilities for Dispatchers and Operation Engineers.

4.1 Real Time VAR Management Integrated Functional Overview

Figure 8 shows a general overview of the Real Time VAR Management application functionality. It also illustrates the relationships among its major functional components: Real Time VAR Management database, information system, generic forecast engine, Network Calculator (NetBas), simulator, visual analysis layer that are used to provide the Operating Authority and/or Operation Engineers with meaningful information.

Figure 8 – Real Time VAR Management Integrated Functional Overview



The Real Time VAR Management application major functional capabilities are:

- **Performance** - The system monitors:
  - The voltage, reactive and active sensitivities and margins reserve at key substation busses. These sensitivities will be used to identify the impact that a marginal load increase, at the critical buses, will have on the state of the network. The system calculates the voltages changes for increases in active and reactive. In addition, reactive reserves are calculated for selected critical buses to identify how much it is possible to increase the load at specified buses before voltage instability occurs.
  - The Control Area's overall VAR management performance against WSCC or NERC standards established in NERC Policy 2, Policy 10 and WSCC/RRWG. See Table-2.
- **Tracking** – The system tracks a variety of measured and calculated values extracted from the CAISO's PI data system. The following is tracked:
  - The reactive reserve margins and the difference from the standard, after it is calculated (CAISO compliance with NERC/WSCC guidelines).
  - The average temperature for every hour of the day, to feed the NetBas model.
- **Probabilistic Prediction** - The forecast capability allows Security Coordinators to make prudent and timely decisions for reliable grid operation. Probabilistic short-term forecast of load (MW) and the resulting reactive reserve margins and voltages sensitivities coming from NetBas, will allow for more efficient planning and allocation of system resources. The forecast shall be done using:
  - NRTF – the Near Real Time Forecast models calculates short-term probabilistic predictions of CAISO's loads. The load forecast program NRTF examines the +3 hour time horizon in 15-minute intervals.
  - NetBas. Forecast load, net interchange, generation schedules and network configuration and resources are input for the NetBas. NetBas calculates system voltages, the sensitivities and active and reactive reserves and flows in the network.
- **Simulation** – The VAR Management application is designed to run interactive simulations for "what if" assessments and/or self-training purposes, using historical and forecast data

The Graphic-Geographic Visualization subsystem facilitates rapid and accurate interpretation of the results for each function. The subsystem takes advantage of the current visualization technology available. It presents past, current and near term future information in a variety of forms:

- Tabular

- 2-Dimensional and 3-Dimensional graphs
- Geographic Maps
- Concurrent
- Animated visualization

4.2 NERC/WSCC Performance Criteria to comply with Voltage Control Reliability Standards - System Level View

The WSCC voltage stability criteria are specified in terms of real and reactive power margins. These criteria are used to evaluate compliance with voltage schedules at critical sub-stations. All member systems must provide the minimum margins specified in Table 2 below.

Table 2 – WSCC Voltage Stability Criteria

WSCC VOLTAGE STABILITY CRITERIA

Performance Level	**Disturbance** (1)(2)(3)(4) **Initiated By:** Fault or No Fault DC Disturbance	**MW Margin** **(P-V Method)** (5)(6)(7)	**MVAR Margin** **(V-Q Method)** (6)(7)
A	Any element such as: One Generator One Circuit One Transformer One Reactive Power Source One DC Monopole	≥ 5%	Worst Case Scenario (8) 50% of Margin Requirement in level A
B	Bus Section	≥ 2.5%	50% of Margin Requirement in level A
C	Any combination of two elements such as: A Line and a Generator A Line and a Reactive Power Source Two Generators Two Circuits Two Transformers Two Reactive Power Sources DC Bipole	≥ 2.5%	
D	Any combination of three or more elements such as: Three or More Circuits on ROW Entire Substation Entire Plant Including Switchyard	> 0	> 0

Notes: (From WSCC Standards: "Voltage Stability Criteria, Undervoltage Load Shedding Strategy and Reactive Power Reserve Monitoring Methodology")

(1) This table applies equally to the system with all elements in service and the system with one element removed and the system readjusted.

(2) For application of these criteria within a member system, controlled load shedding is allowed to meet Performance Level A.

(3) The list of element outages in each Performance Level is not intended to be different than the Disturbance Performance Table in the WSCC Reliability Criteria. Additional element outages have been added to this table to show more examples of contingencies. Determination of credibility for contingencies for each Performance Level is based on the definitions used in the existing WSCC

Reliability Criteria.

(4) Margin for N-0 (base case) conditions must be greater than the margin for Performance Level A.

(5) Maximum operating point on the P axis must have a MW margin equal to or greater than the values in this table as measured from the nose point of the P-V curve for each Performance Level.

(6) Post-transient analysis techniques shall be utilized in applying the criteria.

(7) Each member system should consider, as appropriate, the uncertainties in Section 2.3 to determine the required margin for its system.

(8) The most reactive deficient bus must have adequate reactive power margin for the worst single contingency to satisfy either of the following conditions, whichever is worse: (i) a 5% increase beyond maximum forecast loads or (ii) a 5% increase. The VAR Management will calculate, display and archive these margins and identify those network points that will not meet the WSCC criteria.

The criteria noted in Table 2 apply equally to the system with all elements in service as well as the system with one element removed and the system readjusted. System adjustments after one element is removed in the base case (for performance levels A-D analyses) include all adjustments that can be made within 60 minutes to bring the system to the next acceptable steady state operating condition following the removal of the element (e.g., generation re-dispatch, start up of new generation, phase shifter and tap changer adjustments, area interchange adjustments, etc.).

The margin should be provided at all critical buses during all stressed system conditions. Stressed cases represent worst-case conditions for various load levels and interface flows such as:

- Peak load conditions with maximum generation
- Low load conditions with minimum generation
- Maximum interface flow conditions with worst load conditions.

The WSCC Reactive Power Research Work Group (RRWG) recommends that no less than a 1 in 2 year probability load forecast for voltage stability studies of load serving areas should be used. The 1 in 2 year occurrence load forecast (also referred to as a “50/50” or average load forecast) represents a forecast with a 50% chance of being exceeded in each forecast year.

Determination of credibility for contingencies is based on the definitions used in the WSCC Reliability Criteria. Appropriate measures must be taken to ensure that the margin criteria are met. Reactive power margins must be monitored and maintained in real-time.

The VAR Management Network Calculation engine, NetBas, calculates and archives the parameters required for the following assessments:

V-Q (Voltage (V) vs. Reactive Power (Q)) analysis provides a way to investigate the potential for voltage collapse during the post-transient period within 3 minutes after a disturbance. Besides having sufficient voltage control devices to sustain credible contingencies, it is prudent to have enough margins to account for variations in system conditions. The effects of these variations are considered in the determination of the required reactive power margin. For the V-Q methodology, the reactive power margin is measured from the bottom of the V-Q curve to the V axis. If reactive power compensation is used, the margin is from the bottom of the V-Q curve to the intersection of the V-Q curve and the compensation characteristic.

P-V (Real Power (P) vs. Voltage (V)) analysis is a steady-state tool that develops a curve, which relates voltage at a bus (or buses) to load within an area or flow across an interface. Bus voltages are monitored throughout a range of increased load and real power flows into a region. In the P-V methodology, the MW margin is measured from the nose point of the P-V curve to the operating point on the P-V curve.

The criteria include the following provisions for application to internal systems:

- Controlled load shedding is allowed for Performance level A contingencies in order to meet the margins specified in Table 2.
- The margins in Table 2 do not have to be met if (a) the local area is radial or is a local network and (b) the contingency under consideration does not cause voltage collapse of the system beyond the local area.

Sensitivities will be calculated to probabilistically predict whether the network is approaching voltage instability. The following sensibilities will be calculated:

- Change in reactive by increasing active power
- Change in reactive production for an increment of reactive power
- Voltage changes for increases in active power, and
- Voltages changes for increases in reactive power

4.3 Real Time VAR Management – Probabilistic Prediction Requirements / Capabilities

The Real Time VAR Management probabilistic prediction provides CAISO with very accurate near real time load forecasts. NRTF (Near Real Time Forecast) is the model used for CAISO's load probabilistic predictions up to 3 hours. The NRTF model uses the most recent hourly actual data to adapt its model parameters automatically. The NRTF forecast model has been defined and tuned to get the best probabilistic predictions for the CAISO's load.

The NetBas program uses predicted load data from NRTF with network configuration and resources to predict voltages in all the buses and real and reactive power requirements to maintain voltages within reliability standard thresholds for both normal and contingency conditions. In other words, the NetBas advises the user of what the voltage and margins will be with the current schedules and predicted load. Using this information the Coordinator can modify current plans or evaluate contingency assessments.

5 VISUALIZATION SUBSYSTEM

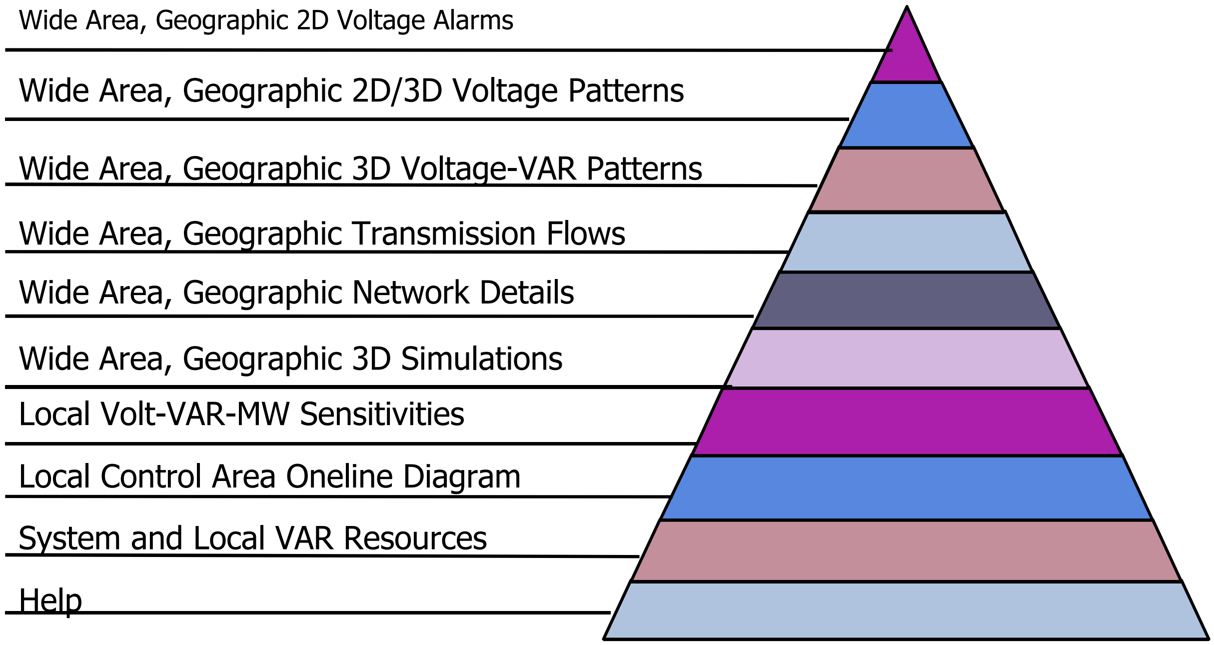
The VAR Management components definition described in Table 3 follows a very generic process where the responses to three fundamental questions, what, why and action for the three time horizons were discussed and preliminary agreed. The responses to these questions served to define the informational visual components and perspectives for this application.

Table 3 – Visual Analysis Definition Process

Visual Analysis Tools Horizon	*WHAT* is Happening	*WHY* is Happening	*ACTION* Corrective Predictive
Performance (Last 1m-24h)	Alarms, 2D/3D parameters pattern	Superposition of cause and effect	Distances from collapse point
Tracking (Last 1d-30d)	Control parameters deviation from reliability standards	Deviation from reliability standards	Probabilistic approach. To be defined
Prediction (Next 1h-48h)	Near real time predictions for key parameters	Causes prediction based on effects predictions	Pattern recognition approach. To be defined
Simulation	10 most recent and 10 near real time predictive cases	10 most recent and 10 near real time predictive cases	10 most recent and predictive cases with worst outages

The design criteria for the User's visual components layout is following an equivalent approach to the one traditionally used for SCADA and EMS displays. It has been demonstrated by Dispatchers that the more effective displays are those that follow a hierarchical approach to present operational data. In this approach, very critical system data is presented on very simple system displays. From the high-level system displays, Dispatchers can go to lower level displays in the hierarchy. Figure 9 shows the various levels of visualization in the Real Time VAR Management system. Most displays are 3D or 2D graphic- geographic displays. Animated displays are used for security assessment simulation and self-training.

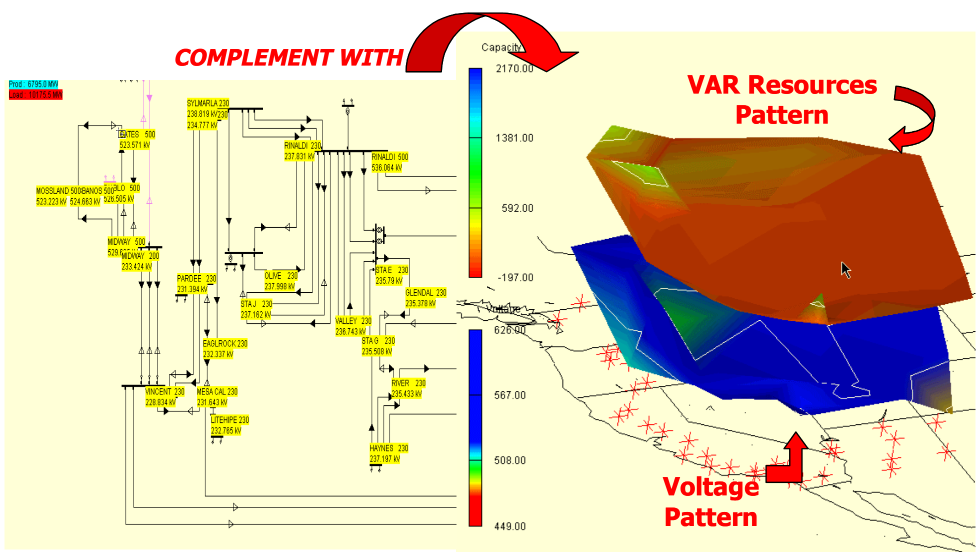
Figure 9 – Hierarchical Levels for VAR Management Visual Analysis



5.1 Graphic-Geographic Visual Components

Figure 10 indicates the overall visual approach this application is offering in the area of user interface by complementing traditional one-line diagrams with graphic-geographic visual components at the higher levels of the display hierarchy. The 3D graph for voltages and reactive resources shown is part of the visual analysis hierarchy shown in Figure 5.

Figure 10 – New Geographic / Graphic Visualization Technologies



5.1.1 Master Visual Perspective

In Figure 11 you can see how the visual perspective is comprised of three views in three separate panels. The labeled portions of the display are:

Section A - In the upper right corner are the buttons to bring the visualization perspectives for the Ancillary Services and other applications perspectives.

Section B - On the bottom of the display is a text area with:

- General information related to the time and date of the data displayed.
- System data for:
    - g) Total Generation capacity in MW and MVAR (This last as GnQ-Min and GnQ- Max)
    - h) Generation (current) in MW and MVAR
    - i) Load, in MW and MVAR
    - j) Losses, in MW and MVAR

Section C – On the upper left corner are the tabs that control the information displayed in the Master Visual Perspective:

- 3D Voltages
- 3D Voltages / VARS
- Voltages (Geographical 2D-presentation)
- Substations Names
- Transmission Lines (animated display)

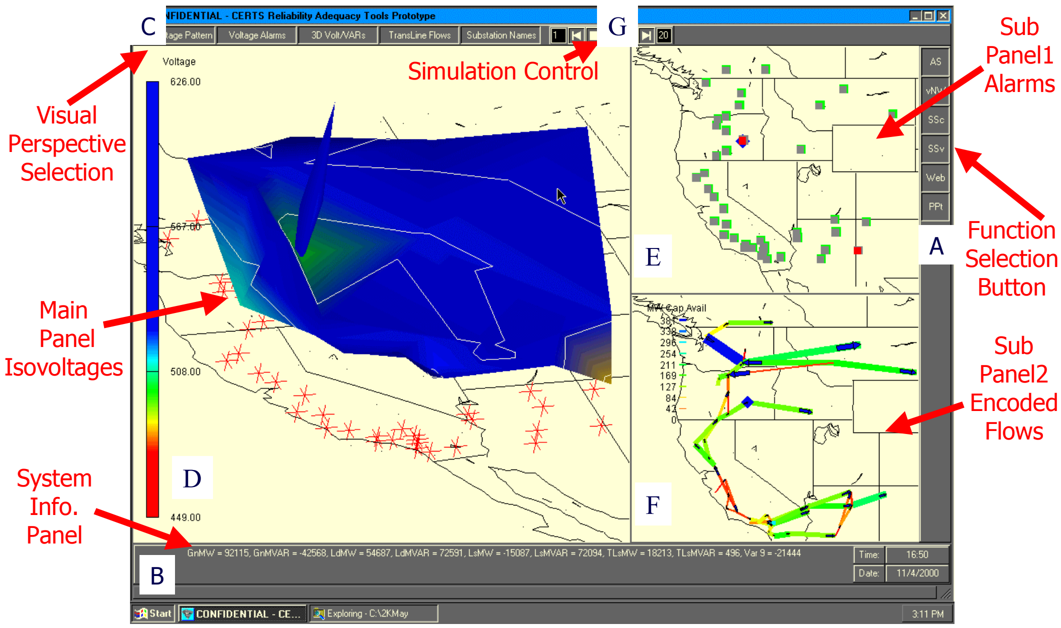
Section D Master Visual Perspective - the main display. The picture shows the WSCC map and the 3D graphs representation for voltages. On the left side is displayed the color bar(s) which represent the spectrum measured values. Here it is voltage.

Sections E and F are fixed sub panels, which display:

- Visual component for voltage alarms for under voltages.
- MW capacity used by the transmission lines. Line color and thickness are a function of capacity available.

Section G shows the “VCR” controls for running simulations. User can select how many past or future cases to simulate and start/stop the simulator with start/stop buttons.

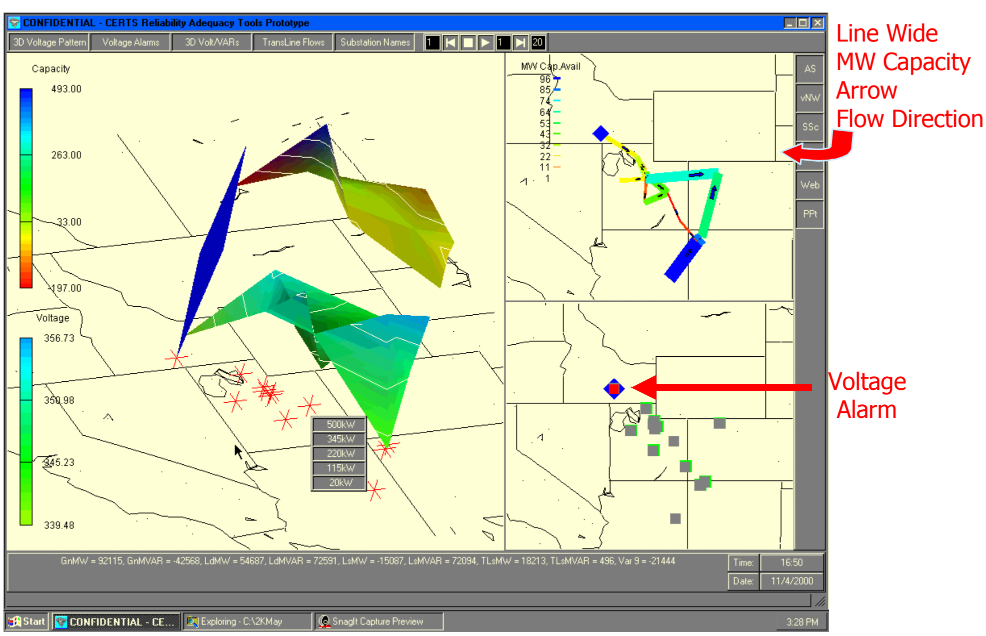
Figure 11 – Master Visual Perspective



5.1.2 3D Voltage / VAR Perspective

Figure 12 shows the 3D Voltages/VARS display. The 3D surface maps of voltage and reactive-reserves are in the main display window. The corresponding voltage alarms and transmission flows are shown in the subpanels.

Figure 12 – Voltage / VAR Master Visual Perspective

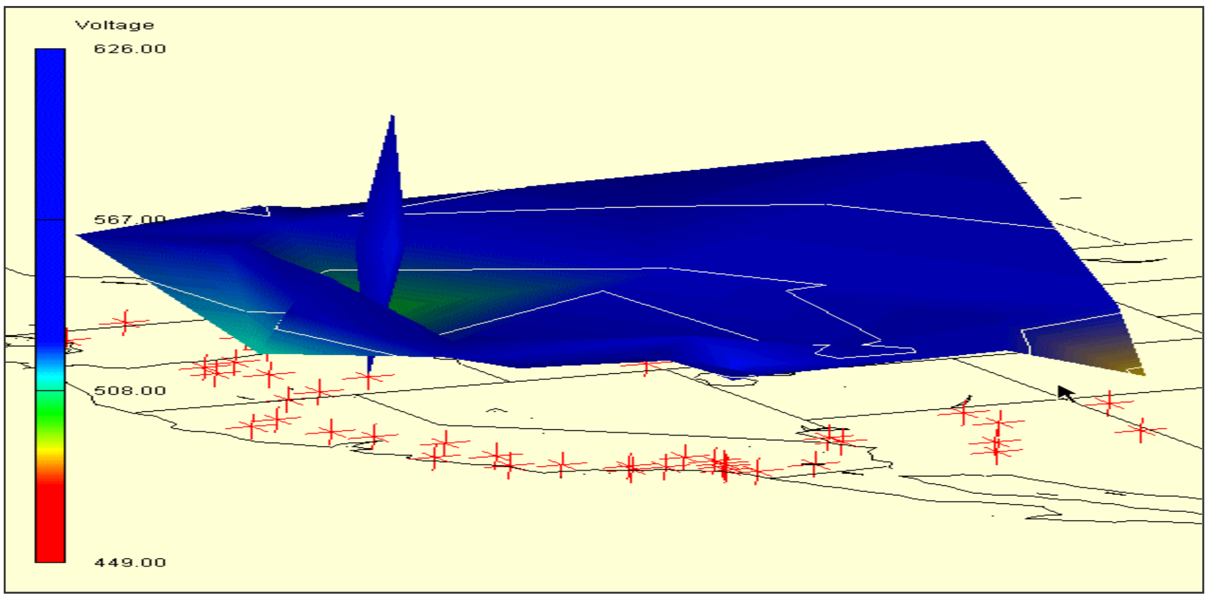


5.1.3 3D Voltage Patterns

Figures 13 shows a 3D presentation of the voltage using a surface map, with a voltage scale colors, superimposed over the WSCC map. The figure corresponds to a NetBas run. Red indicates the area with the lowest voltage condition. Areas with yellow and green are on the borderline of lowest critical voltage.

The red stars on the map indicate the geographical locations of the monitored substations. The view can be rotated, panned and zoomed using the mouse buttons and the control/shift keys. Different voltage levels can be selected with the right mouse click.

Figure 13 – 3D Voltage Patterns

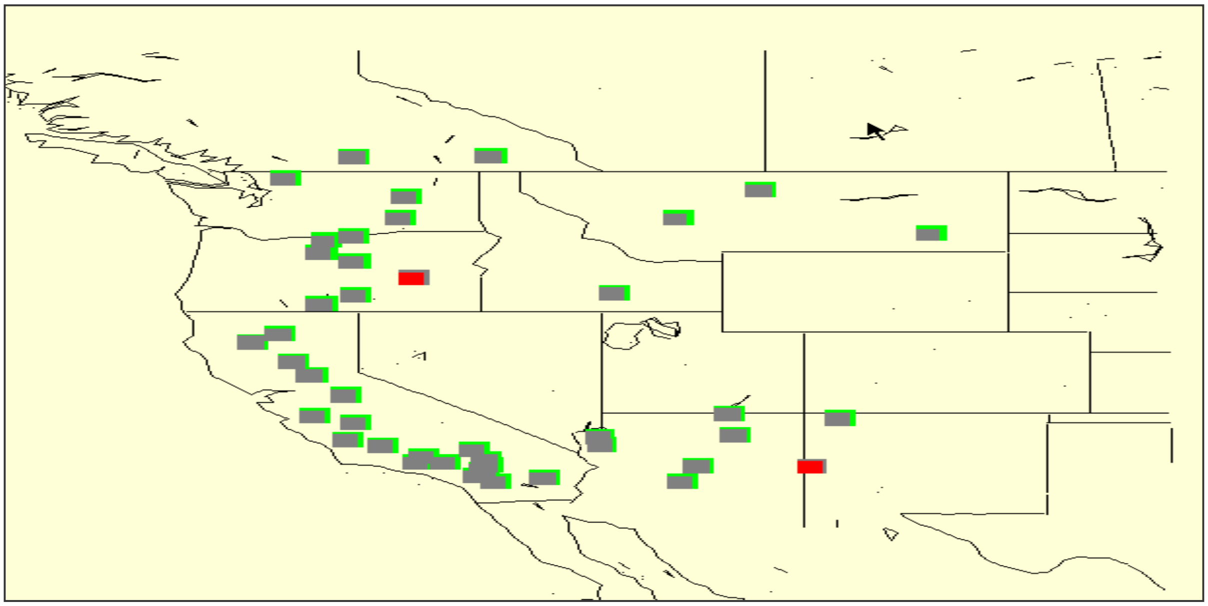


5.1.4 Voltage Alarms

Figure 14 shows the WSCC map with the monitored substations voltages depicted using two overlayed rectangles. The external rectangle represents the nominal substation voltage. The internal rectangle represents the measured actual voltage in the substation.

When the internal rectangle is smaller than the external but its size is close to the external rectangle it means that the voltage in that substation is close to the nominal voltage. The blinking rectangles in blue color alarm those substations with voltage below 5% of the nominal voltage.

Figure 14 – Voltage Alarm Visual



5.1.5 Voltage Patterns with Corresponding VAR Resources

Figure 15 shows both the voltage and VAR results together. The values are presented in the form of a 3D surfaces. In this display, the calculated VAR values are added as another surface map. The purple and blue colors represent the negative reactive profile. The positives are represented, according with the color-scale-bar in the left side, by red and green colors.

Figure 15 – Voltage / VARS Patterns

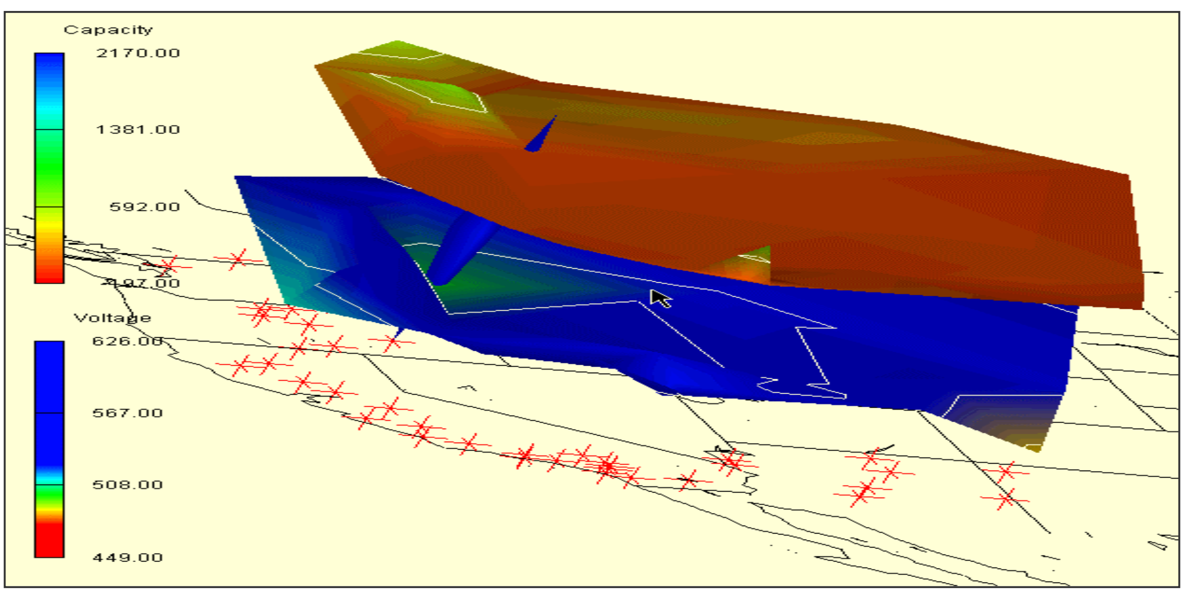
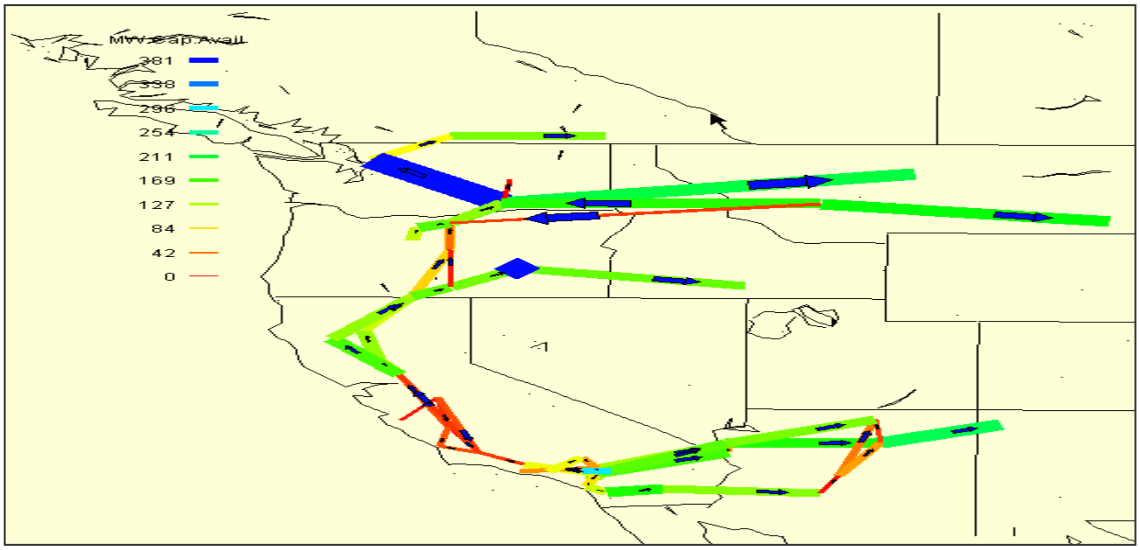


Figure 16 – VAR Flow Animation Transmission Line VAR Flow Animation

Figure 16 is a display that shows the flow of VARS on the interconnected transmission lines. The thickness of the lines, and its color code, are associated to the reactive power capacity shown in the left scale of values. The arrows over the lines and its colors represent the direction of VAR flows.

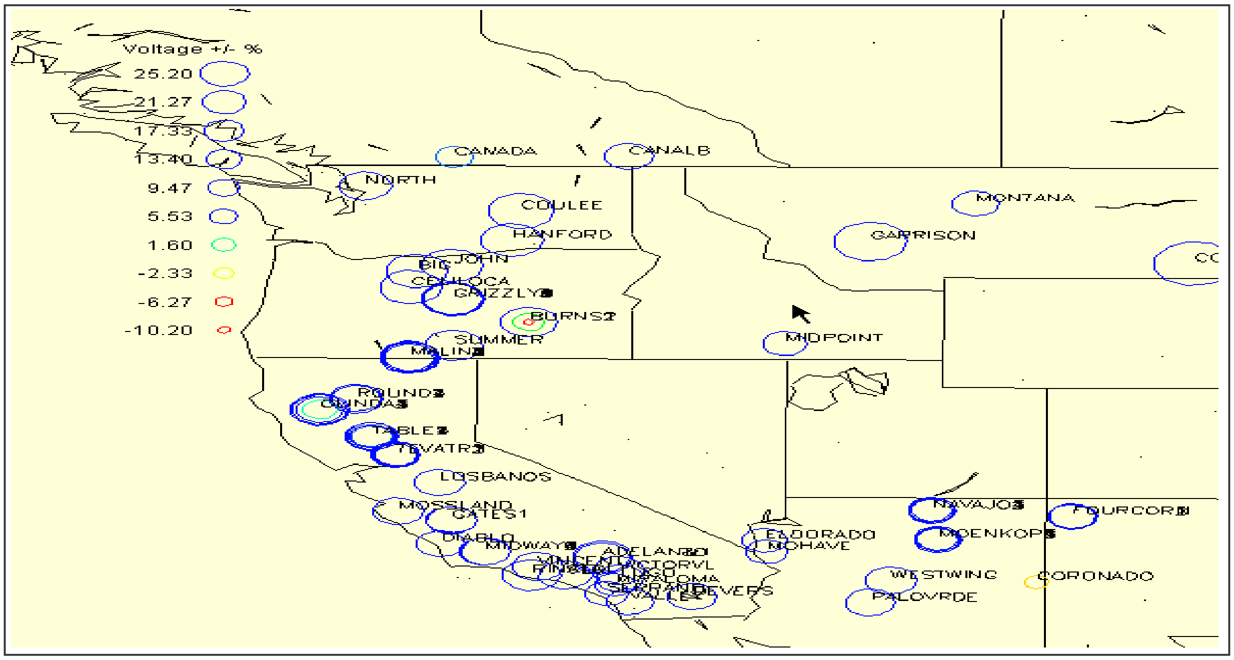


5.1.6 Substation Display – Name and Voltage

Figure 17 shows the WSCC substation locations. The circles indicate the voltage level in the substation. The color of the circle indicates the voltage deviation from nominal. The scale at left shows the magnitude and direction (above or below) of the deviation.

Blue circles mean that the voltage is over the nominal. Red circles mean that the voltages for those substations are under the nominal voltage. Green and yellow circles mean that the voltages for those substations are close to the nominal voltage (green up and yellow down)

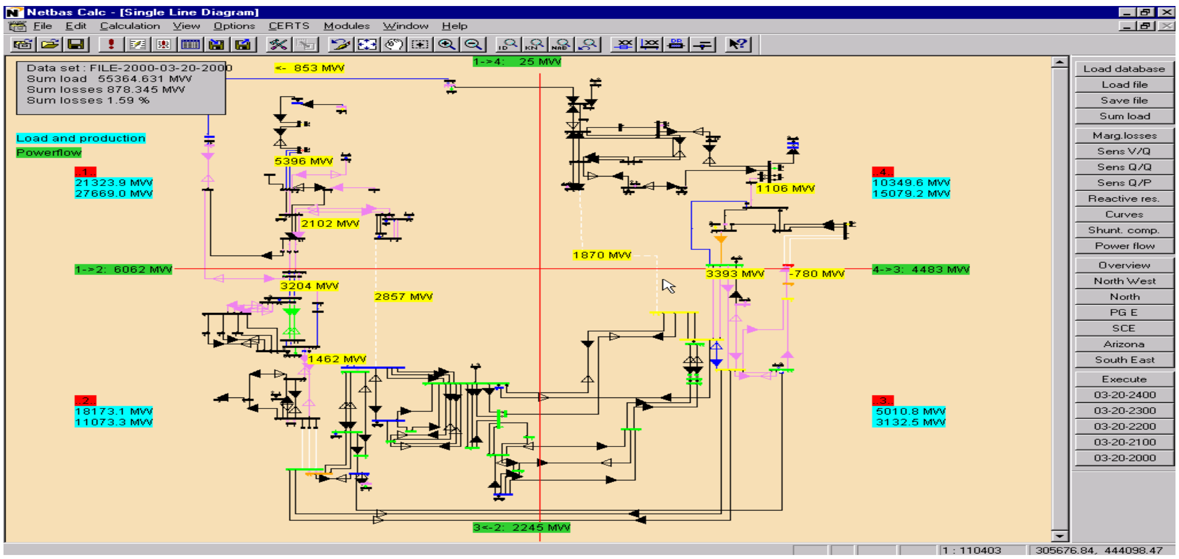
Figure 17 – Substation Names and Voltages



5.1.7 One-Line Diagram

Figure 18 shows a more complex visual display of the network details. The one-line diagram has 4 Areas identified with the area numbers in red. Below them the numbers with the blue background show the Area's net load and the power production. Numbers inside the diagram with background in light green show the active power flows. Those numbers with background in dark green show the magnitude and the sense of the power interchange between the indicated Areas. Arrows in the lines indicate direction of MW (solid) and MVAR (empty) flows. The buttons in the right side of the screen are the diverse options to get to deeper levels in the visual analysis structure. The buttons in the upper side allow selection of different functions from the NetBas network calculations

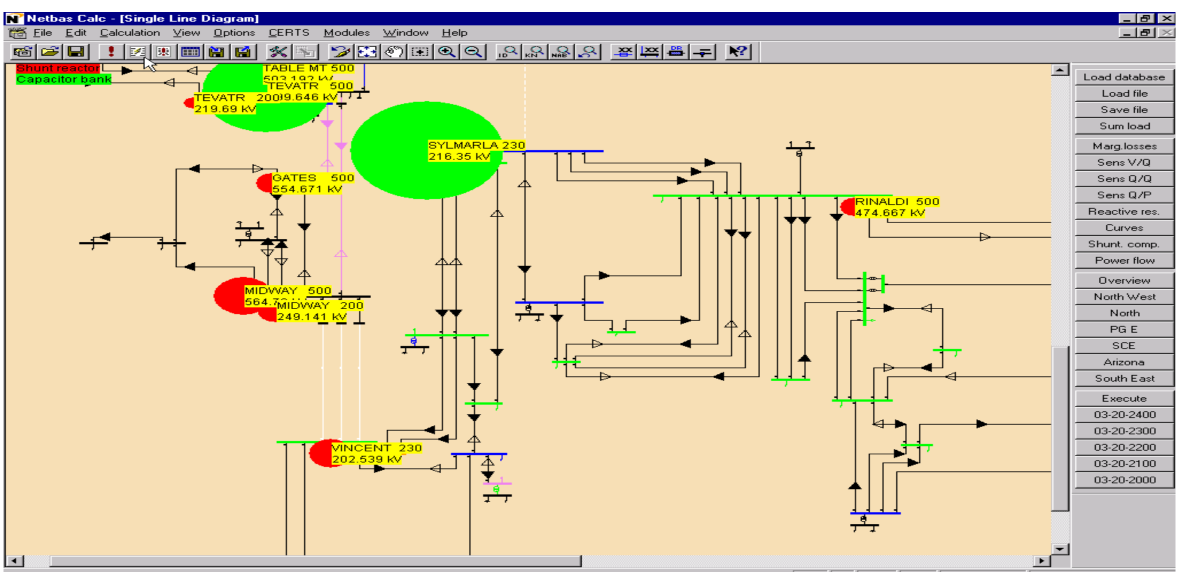
Figure 18 – One Line Diagram Visual Component



5.1.8 Shunt Reactor and Capacitor Bank Reserves.

Figure 19 shows the compensation reserves in the network as dark green circles. The red circles show the location and the capacity of the shunt reactors and the green ones show the capacitor bank reserves. The names and the numbers with the background in light green show the names of the substations and the actual voltage on those stations.

Figure 19 – Shunt Reactor and Capacitor Bank Reserves



5.1.9 Sensitivities V-Q and Q-P

Figures 20 and 21 show the V-Q and Q-P voltage sensitivities respectively. The red bars represent positive values and blue bars the negative values. Labels and numbers with background in light green color show the names of the substations and sensitivity values represented by the bars. The labels with orange and pink background show the biggest positive and the lowest negative sensitivity values.

Figure 20 – V-Q Sensitivity

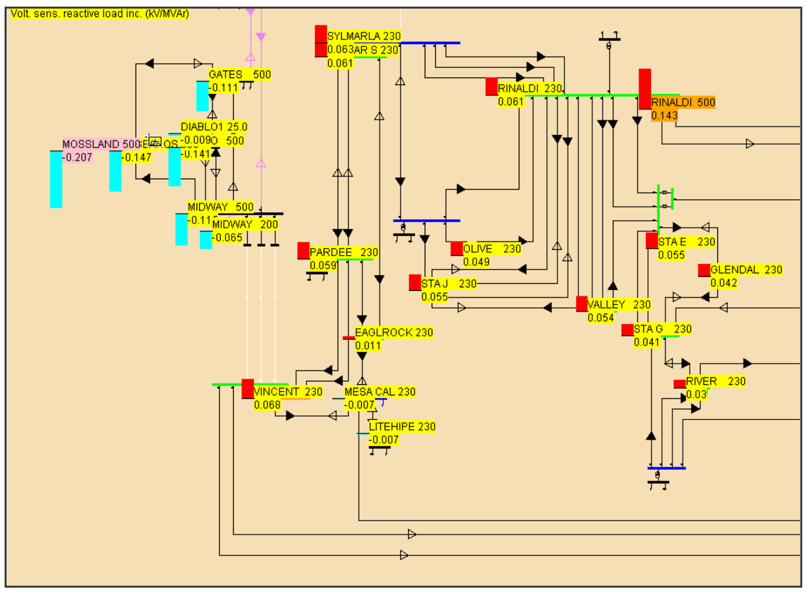
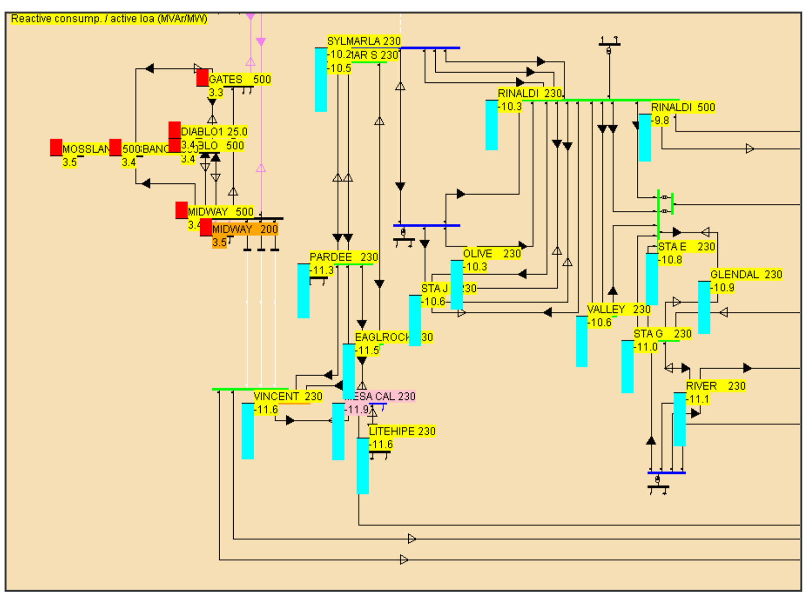


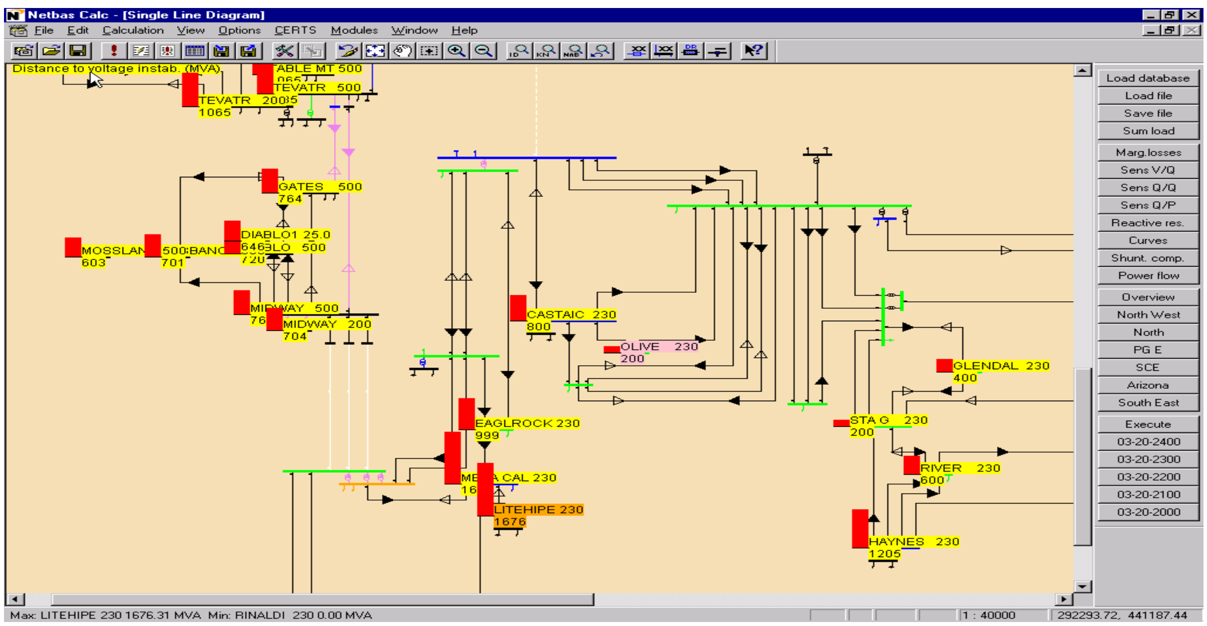
Figure 21 – Q-P Sensitivity



5.1.10 Distance to Voltage Instability

Figure 22 goes deeper into the visual analysis hierarchy, and shows the voltage instability pattern for the network. Those stations with the bigger red color bars are far from voltage instability and those with the small red color bar are closer to critical voltage stability condition. Labels and numbers with background in light green color show the names of the substations and the value distance to voltage instability in MVA. The substation with the most critical voltage stability condition is shown with background in pink color, and that one that is far to voltage instability is shown with background in orange. The buttons in the right side of the screen are the diverse options to get to deep levels in the display hierarchy. The buttons in the upper side allow selection of different functions from the NetBas.

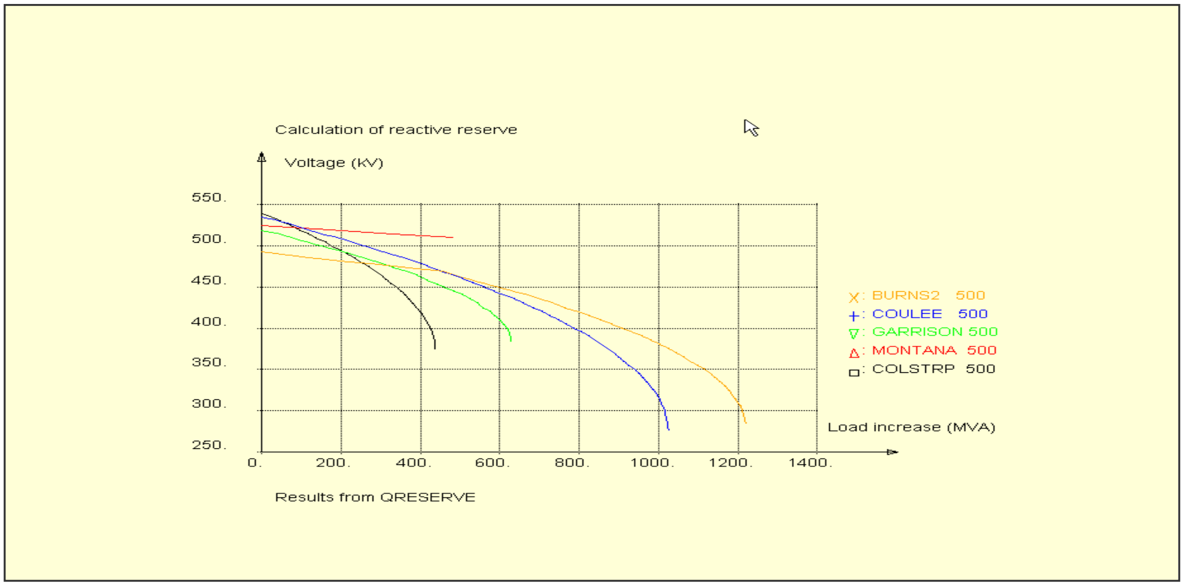
Figure 22 – Distance to Voltage Instability (MVA)



5.1.11 Reactive Reserve Margins

Figure 23 provides the user deeper details in the form of an x-y plot. The figure shows final reactive reserve calculations for selected stations from the NetBas. The calculator incrementally adds load until the selected stations reach instability. Figure 20 shows the voltage as a function of load increase. The distance from the origin to the largest x-axis value on each curve is the distance to voltage instability.

Figure 23 – Reactive Reserve Margins Visual Component



5.1.12 Voltage VAR Visual Monitoring, Analysis and Assessment Process

The analysis process is comprised of 6 steps using the informational visualization displays. The 6 displays in Figure 24 show what the Security Coordinator would use to identify:

- voltage abnormal events
- the relationship with reactive-reserves conditions
- the sensitivities at critical buses
- loading distances before voltage collapse

Step-1 – 2D Voltage Flashing Alarms – Visual component showing specific stations with voltages under predetermined thresholds.

Step-2 – 3D IsoVoltage Patterns – Visual component showing some specific stations as in step-1 but in a graphic 3D display with isovoltage contours included.

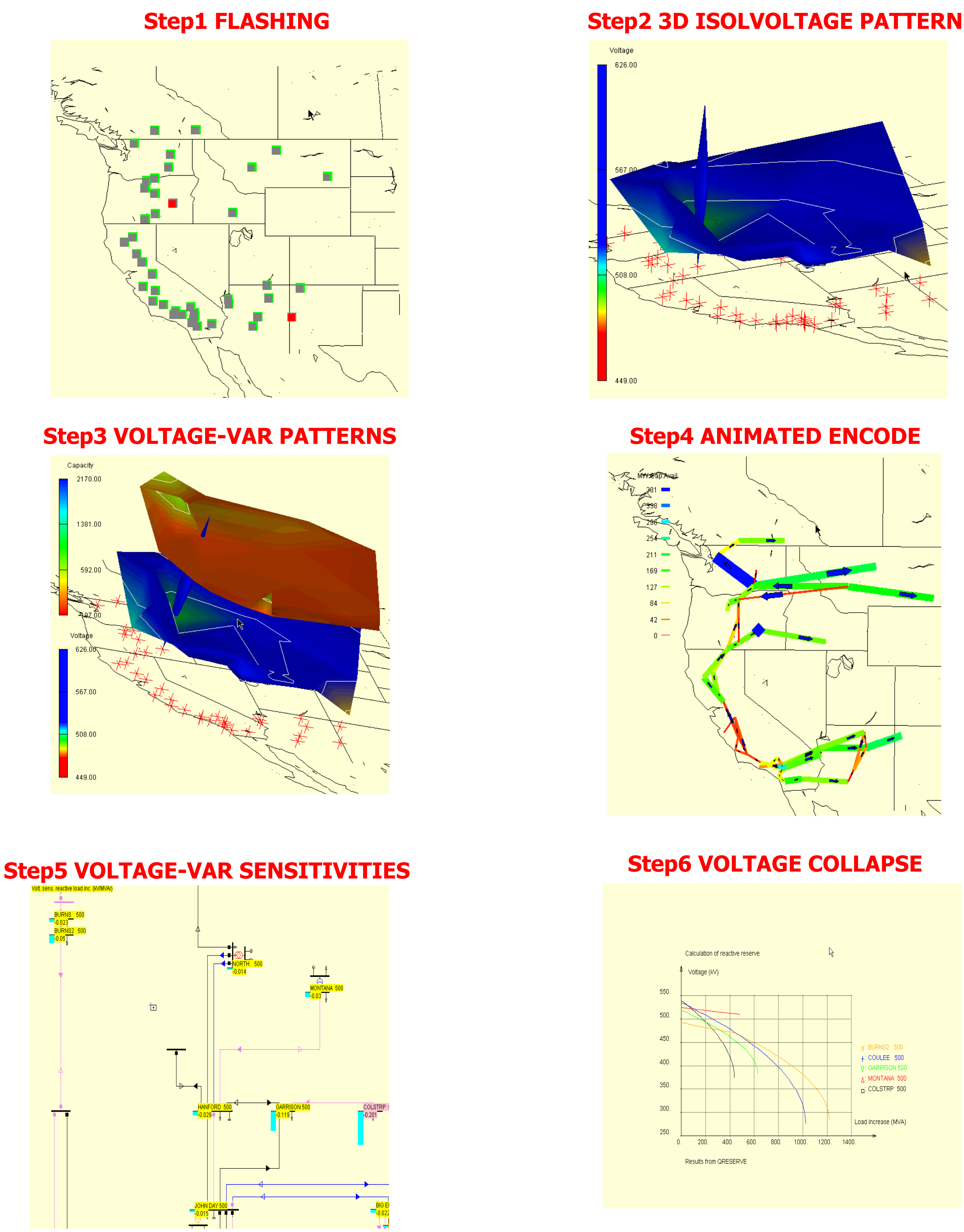
Step-3 – Voltage / VAR Patterns – Visual component that correlates voltage trouble- areas with corresponding reactive reserve patterns.

Step-4 – Animated / Encoded Flows – Visual component showing the power flows with line-capacities and flow direction encoded with line-wide an animated arrows.

Step-5 – Voltage Sensitivities – Visual component with vertical bars in a one-line diagram showing voltages changes to marginal load increase for pre-selected buses.

Step-6 – Voltage Collapse Distances – Visual component showing how much it is possible to load up pre-selected buses before voltage instability occurs.

Figure 24 – Control Visual Monitoring, Assessment and Analysis Process



5.1.13 Preliminary Probabilistic Predictions User Interface Capabilities

The Probabilistic Predictor writes its forecast and probability results into Real Time VAR Management time-series oriented database. The visualization modules take the results from the database and displays them in graphic or tabular displays predefined by users. The Predictor's user interface displays will be designed to be geographic oriented, user friendly and intuitive. The displays will show information in a logical and consistent manner, and appropriately guide Dispatchers through the interpretation of results.

5.1.14 Data Mining with Trellis-graphs Visualization, Sample for Load, Clusters Displays

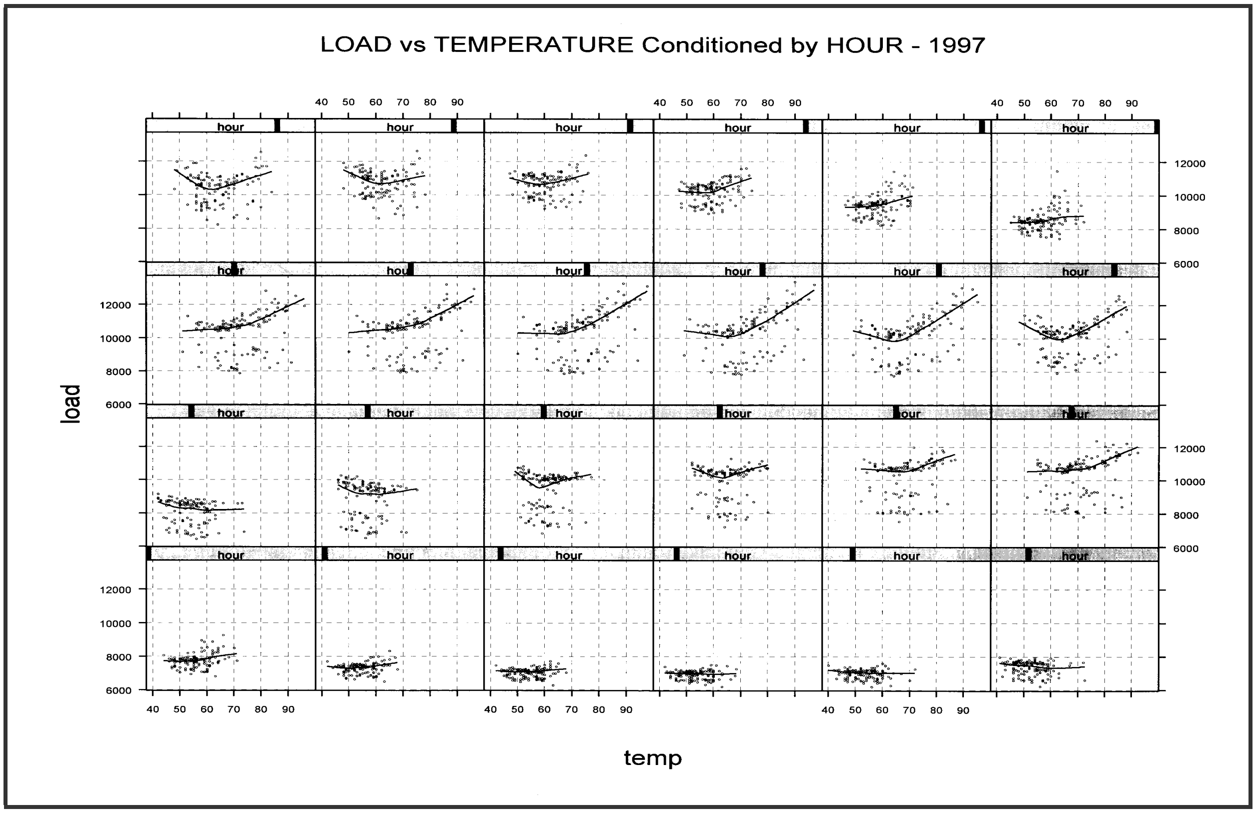
The VAR Management time-series oriented database has data mining capabilities for extracting valid, previously unknown, comprehensible data relationships and patterns that are not obvious to dispatchers and engineers. Cluster identification is one of these capabilities aimed at finding similar parameters sharing a number of useful properties.

Figure 25 is an example showing visually (Conditioned-graph) the correlation (sensitivity) of load for a range of temperatures for each hour of the day. The graph has been created using historical data for a region of the California power system for each hour during the year 1997. Equivalent graphs can be created for any three or four parameters and any time period such as holidays, weeks, months, etc.

For each hour, represented by a box or a cell of the graph-matrix, the graph shows the historical load sensitivities for a range of temperature values (graph of load vs. temp). The hour is indicated as a bar in the top of each cell and the number in the left or the right corresponds to the load scale. Numbers in the bottom and in the top are temp scale for each cell. Note the left side of the inflection points for most of the hours of the day where load decreases even if temperature increases.

Using data mining with conditioned type graphs visualization, Dispatchers and other users can improve their ability to forecast load. If they know the expected value of temperature for each hour, they can see on the graph the load sensitivity for a given variation of the temperature for any hour of the day. Having this capability will allow the user to improve their decisions in allocating resources efficiently and reliably.

Figure 25 – Load – Temperature-Hour Relationships-Conditioned Cluster Display



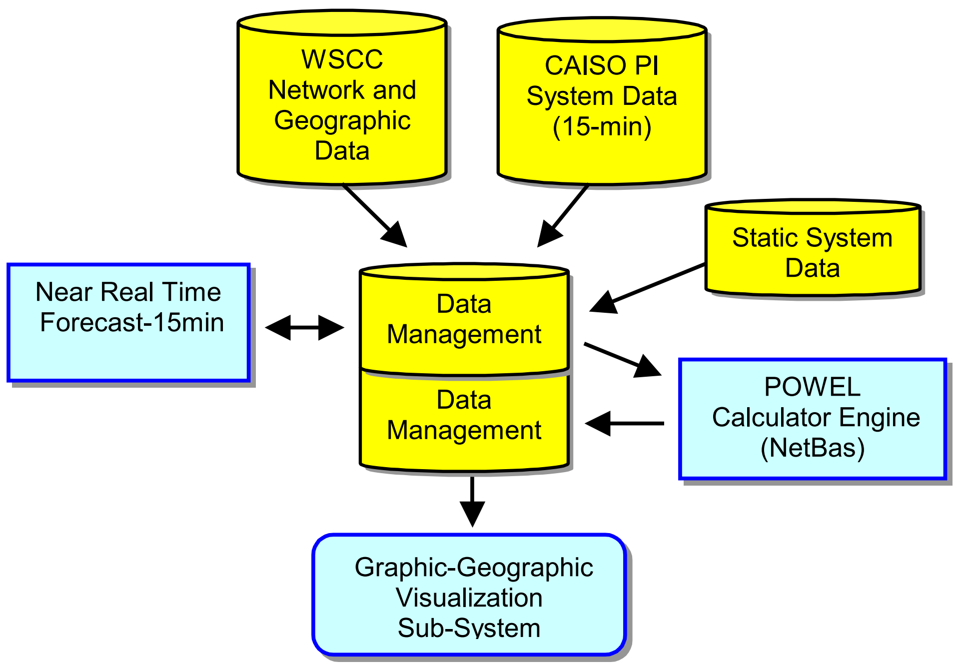
6 DESIGN SPECIFICATION

The Real Time VAR Management application has been designed to comply with the four main functions: performance, tracking, prediction and simulation.

6.1 Real Time VAR Management Overview

Figure 26 is an integrated high-level view of the Real Time VAR Management design and its primary components.

Figure 26 – Real Time VAR Management Application Integrated Functional Infrastructure



The following are functional overviews for each of the components layers:

- **Graphic-Geographic Visualization** – The visualization subsystem enhances the interpretation of the modeling results. It incorporates geographic, graphic, and tabular information as well as animated presentation of results. The visualization layer is integrated in a modular approach using ActiveX technology and simple formatted file exchange. This integration method allows extension and enhancement without extensive software modification until the system is taken into production mode.
- **Near Real Time Forecast NRTF** - The NRTF Engine is a statistical model used to forecast the load up to 3 hours in advance in 15-minute intervals.
- **Powel Network Calculator NetBas -** This program calculates voltages in all the system busses, sensitivities for key busses, and real and reactive power flow in the

network's lines. This program uses the load predictions from NRTF.

- **Data Management**. There are two major elements of data management. The first element supports data collection from the CAISO PI system, the WSCC Network data, and the static/non-PI system data. It also manages the input and output for the NRTF model, and supports the mapping of the data into NetBas. The second element is the interface between the NetBas system and the Visualization subsystem.
- **WSCC Data** – contains the network topology and configuration data for the transmission network.
- **CAISO PI Data** – contains the near real time updates of measured values extracted from the EMS.
- **Static System Data** – contains data that is not updated through the PI system.

6.2 Near Real Time Forecast Model Description, Calibration and Expected Accuracy

The Near Real Time Forecast Engine is a statistical model and is used to forecast the load and other parameters up to 3 hours in advance in 15-minute intervals. It has been designed using a generic integrated approach that allows for future timeframe changes.

6.2.1 Forecast Processes Description

To assure data quality, the NRTF filters all the raw data received from the PI system. Good data points are left unaltered, while gross outliers (out of the data range) are replaced by statistically filtered interpolates. The bad data is replaced, but retained in the database for archive and tracking purposes. To improve the forecast accuracy the NRTF allows using the most recent actual-historical data available to adapt to most recent conditions the forecast model parameters.

Output Data – The probabilistic prediction has the following types of outputs:

User Adjustable (Incremental Rates)- The probabilistic prediction calculates and displays hourly the CAISO load change as function of temperature (MW/ºF). Schedule Coordinators can modify the probabilistic prediction interactively. If the CAISO uses the load variation table as a function of the temperature, the Coordinators can perform some "what if" scenarios:

> What will the load forecast be if the temperature increases by 1º F? The Coordinator enters the value of the expected temperature increase (1ºF) in a specific region of the control area and the NRTF will adjust the former load probabilistic prediction and show the new load profile..

Graphical and Tabular Interfaces. Results of forecast models and data mining results are presented to the Operating Authority using effective graphic aids. These types of outputs will allow an easy interpretation of results.

The model errors indicate the deviation between the actual dependency between load and temperature, and the dependency described in the model parameters. The MAPE is the mean or average of the percentage errors of all the projected data in a forecasting model versus the actual data. See example of MAPE calculation at the end of this section.

The NRTF model can run in automatic mode. This facilitates forecasting of multiple forecasting zones.

6.2.2 Models Calibration and Tuning

The Calibration Process is the initial phase during which the model parameters are defined and tuned to obtain the best accuracy.

6.2.3 Models Accuracy Performance

The expected predictor accuracy results from Table 4 have been identified for a typical utility using actual historical data. The accuracy results are described below.

Table 4 – Accuracy Results for Near Real Time Forecast Load

Probabilistic Forecast – Target Forecast Accuracies

NRTF Model	Less than 0.3%		Less then 0.4%		Less then 0.5%		Less than 0.6%	
	On-peak	Off-Peak	On-peak	Off-Peak	On-peak	Off-Peak	On-peak	Off-Peak
1 Hr Ahead	50%	50%	100%	100%	100%	100%	100%	100%
2 Hr Ahead	25%	25%	63%	63%	100%	100%	100%	100%
3 Hr Ahead	17%	17%	42%	42%	85%	85%	100%	100%

NOTES: CAISO targets were obtained from September 1999 forecast results

Table 4 shows the target-forecast accuracy and the probabilistic results obtained by CERTS during a test using real data. The load probabilistic predictions used four levels of expected accuracy (on peak and off peak) for each time horizon (1, 2, or 3 hours ahead) for. For example, for 3 hour ahead, the model predicted the on peak load (MW) with less than .6 % error, 100% of the time.

The accuracy performance results showing in Table 4 were calculated using unbiased Mean Absolute Percent Error (MAPE) statistics. An example of MAPE calculations and utilization is shown in Table 5.

Table 5 – Example of MAPE Calculations

COMPUTATIONS OF THE RELATIVE MEASURES FOR A SET OF ERRORS

Period I	Observation Xi	Forecast Fi	Error Xi - Fi	PE (Xi - Fi) *100 / Xi	APE | Xi - Fi |*100 / | Xi |
1	22	24	-2	-9.09	9.09
2	23	28	-5	-21.74	21.74
3	39	32	7	17.95	17.95
4	37	36	1	2.70	2.70
5	38	40	-2	-5.26	5.26
6	47	44	3	6.38	6.38
7	43	48	-5	-11.63	11.63
8	49	52	-3	-6.12	6.12
9	61	56	5	8.20	8.20
10	63	60	3	4.76	4.76
Sums			2	-13.85	93.84

Where APE = absolute percentage error

$$MPE = \frac{-13.85}{10} = -1.385\%$$

$$MAPE = \frac{93.84}{10} = 9.384\%$$

6.2.4 Input Data Filtering Process

This process verifies the data and checks for outliers before the probabilistic prediction process. Invalid data is replaced with statistically valid interpolated values. In addition, input data used by the NRTF are classified into three basic categories; weekdays, weekends, and holidays. Using these three categories will improve forecast accuracy.

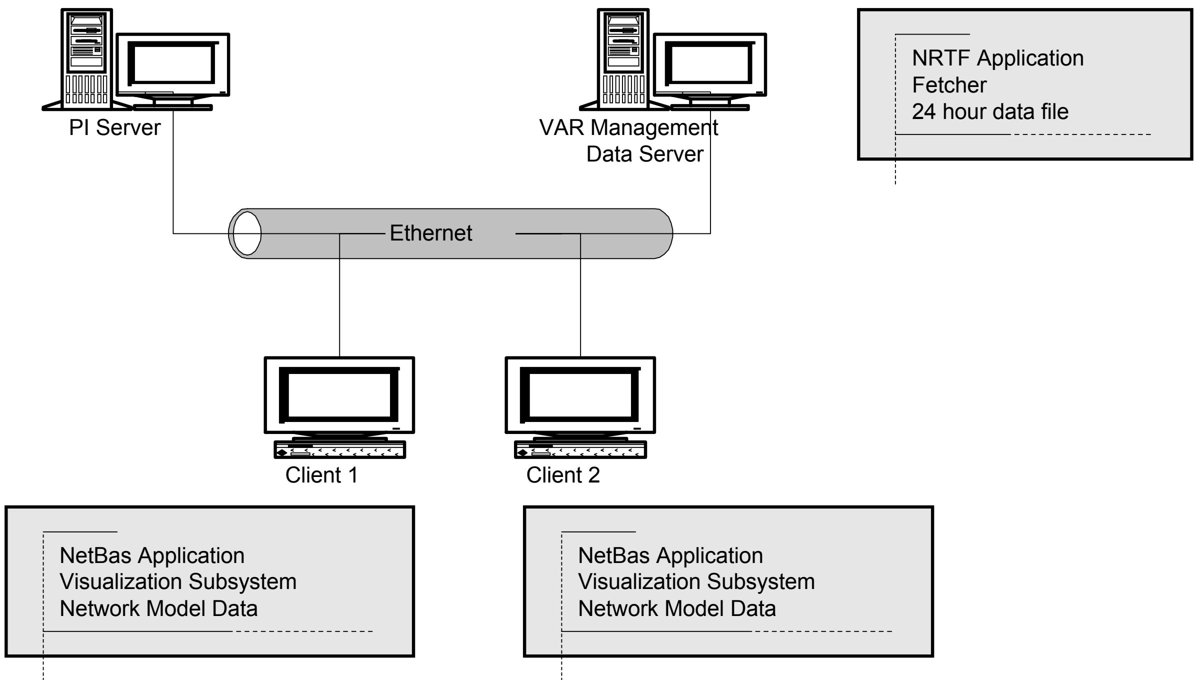
Filtering is fully automatic, and follows the steps listed below:

- Read the current raw data (extracted from the PI database)
- Categorize the data for weekdays and holidays
- Check for missing data
- Verify that the data is greater than zero and not out of statistically acceptable range (an outlier)
- Replace missing data or outliers with smoothed, interpolated value (the smooth interpolated value are calculated using a statistical routine and the most recent values for the data)
- Both the new value and the replaced number is saved in the database
- The filtered data is ready for the forecast process

6.3 Real Time VAR Management Hardware and System Software Requirements

The computer and network configuration for the VAR management system requires three workstations and network connections as shown in Figure 27

Figure 27 – VAR Management Hardware / Network Configuration



Following are the main hardware and software components for the Real Time VAR Management desktop workstation.

- Computer Hardware – PC based, network ready workstation. The platform for the Real Time VAR Management application allows users an easy interaction with the application and visualization subsystems. The main characteristics of the workstation will be:

Table 6 – Computer Hardware

Client Machines (2)

Processor:	Pentium® III processor, 733MHz
Memory:	1GB RDRAM
Monitor:	19" Very High Quality Monitor
Graphics Card:	ELSA Synergy Force or equivalent
1st Hard Drive:	18GB Ultra SCSI (15,000 rpm)
Floppy Drive:	3.5" 1.44MB Floppy Drive
Operating System:	Microsoft® Windows NT® 4.0,CD (Service Pack 5)
Mouse:	Microsoft Intellimouse® (2-button w/scroll)
CD Read-Write Drive:	8X/4X/32X IDE CD Read-Write
Additional Software	MS Office Professional

Data Server

Processor:	Pentium® III processor, 933MHz
Memory:	1GB RDRAM
Monitor:	17" High Quality Monitor
Graphics Card:	ELSA Synergy Force or equivalent
1st Hard Drive:	18GB Ultra SCSI (15,000 rpm)
Floppy Drive:	3.5" 1.44MB Floppy Drive
Operating System:	Microsoft® Windows NT® 4.0,CD (Service Pack 5)
Mouse:	Microsoft Intellimouse® (2-button w/scroll)
CD ROM, DVD, and Read-Write Drives:	8X/4X/32X IDE CD Read-Write
Additional Software	MS Office Professional

6.4 Process Performance Parameters

Data Protocols. Three different data protocols are used in the application; one is the data interface protocol with the PI real time data system. This protocol utilizes the PI system's API and TCP/IP for data interchange. The second interface to the NetBas Network Calculator engine using COM. The third interface is with the Visualization Subsystem using ActiveX.

End User Displays Response Time. The system supports multiple users, however the system performance is based upon a single user. Multiple users may experience slower performance.

There are three cases of display response time measurements.

(1) Call a display of existing data

    For case one, the elapsed time between an end user calling a display and the time validated or calculated data already residing in the NetBas results appears on the user display will be less than 15 seconds.

(2) The time required for real time data is extraction from the PI system, the data validation and new forecast and network calculations.

    For case two, the elapsed time after a user requests a display and the new data appears on the display is no more than 1 minute. This case includes the time required for the PI System data transfer, data validation and new forecast/network calculations for a maximum of 1000 time series.

(3) Calling a display simultaneous to the calculation of new network values

    For case three, the elapsed time between a user calling a display of data already in the database, while a new set of network calculations is requested, will not exceed 1 minute.

Data Transfer rates and time limit data storage: The data transfer rates, as well as the time limit data storage for each type of data, are specified in Table 6, in Appendix A under the time resolution specification.

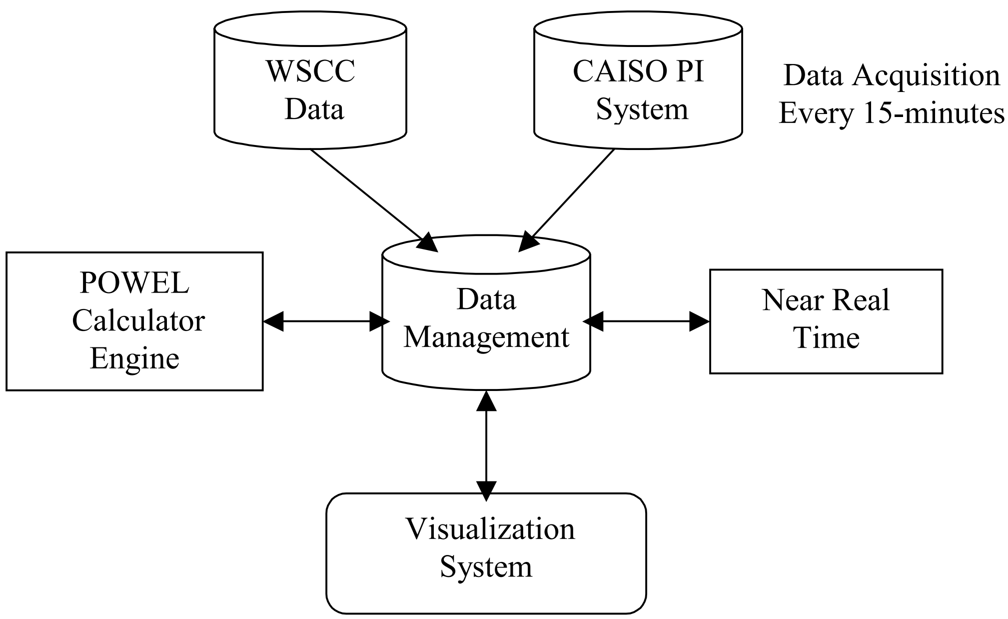
Forecast Accuracies. Target accuracies will be the same as shown in Table 5 in the NRTF Accuracy Section 6.2.3.

6.4.1 Real Time VAR Management Integration Scheme

Figure 28 shows integration of Real Time VAR Management application with the Host input / output system. Automatically, hourly, using data from the CASIO's PI system, the Data Management subsystem will extract the measured data from the PI systems time-series operational database. The Data Management subsystem will monitor control area's performance, track, save and time-tag all the data and calculations, and will start the predictive function. An additional filtering process will clean raw data during the probabilistic prediction process.

Results of the Real Time VAR Management application and the NRTF forecast models probabilistic predictions will be tagged, archived, and taken from the database to be displayed to the System Operators. Data flow is fully automatic without any manual interaction, except for the interaction of the System Operator to override the model's forecasts for accuracy improvement purposes.

Figure 28 – Real Time VAR Management Application High Level View



The following is the summary description of the main processes:

Control Area Reactive Reserves. Hourly, using a PC based application, the CAISO's will save data in a time series oriented database. The data archived will be the control area loads, voltages and reactive reserves.

Data Management. This database will be used to store the entire Real Time VAR Management application's input, filtered and output data, parameters of the models, as well as data mining queries and selected data mining results.

Tracking will be the function to register all input and output data from the performance calculations and comparisons between actual and scheduled values.

Data Filtering and Validation. To assure data quality, the application will include an input data filtering process for raw actual data.

- Hourly Forecast Models. Represents the adaptive forecast models tuned for different real time horizons and whose results are will be saved in the database and presented to the System's Operators and short-term planners. The application also will allow users intervention interactively using actual incremental rates calculated and displayed by the application.

- Models Results Consolidation. Outputs of the different models will be consolidated and also archived in the time series database in order to allow Operating Authority Dispatchers and System's Operators to interact with these results via the Information Management System.

Powel Calculator engine NetBas. The Real Time VAR Management application will run a load flow of the power system periodically, hourly, or on demand, using the load probabilistic predictions from the generic forecast engine to know voltages in all the system's buses and real and reactive power flow in network's lines. The program saves a maximum of 22 cases from the most recent periodic execution.

- Automatic Hourly Forecasts. Displays to show the various forecasts described in the output section. They can be implemented as web pages.

APPENDIX A

SUMMARY OF REQUIREMENTS FOR CAISO HARDWARE / SYSTEM SOFTWARE AND DATA REQUIREMENTS FOR THE VAR MANAGEMENT PROJECT – October 12, 2000

CERTS has summarized the following hardware, system software and data requirements needed from CAISO to be able to continue with the deployment of the VAR Management and project in accord with revision-0925K of the project schedules submitted to CAISO.

7 Hardware / System Software Requirements For The VAR Management Project

- Characteristics of CAISO Security Coordinator Console Workstation

  Processor: Pentium® III processor, 933MHz
  Memory: 1 GB RDRAM
  Monitor: 19” Very High Quality Monitor
  Graphics Card: ELSA Synergy force or equivalent
  1st Hard Drive: 18GB Ultra SCSI (15,000 rpm)
  Floppy Drive: 3.5” 1.44MB Floppy Drive
  Operating System: Microsoft® Windows NT® 4.0, CD (Service Pack 5)
  Mouse: Microsoft Intellimouse® (2-button w/scroll)
  CD ROM, DVD, and Read-Write Drives: 8X/AX/32X IDE CD Read-Write
  Additional Software: MS Office Professional

- Characteristics of CAISO Security Coordinator Support Workstation

  Processor: Pentium® III processor, 933MHz
  Memory: 1 GB RDRAM
  Monitor: 19” Very High Quality Monitor
  Graphics Card: ELSA Synergy force or equivalent
  1st Hard Drive: 18GB Ultra SCSI (15,000 rpm)
  Floppy Drive: 3.5” 1.44MB Floppy Drive
  Operating System: Microsoft® Windows NT® 4.0, CD (Service Pack 5)
  Mouse: Microsoft Intellimouse® (2-button w/scroll)
  CD ROM, DVD, and Read-Write Drives: 8X/AX/32X IDE CD Read-Write
  Additional Software: MS Office Professional

- VAR Management Data Fetcher from CAISO-PI System

  Processor: Pentium® III processor, 933MHz
  Memory: 1 GB RDRAM
  Monitor: 19” Monitor
  Graphics Card: ELSA Synergy force or equivalent
  1st Hard Drive: 18GB Ultra SCSI (15,000 rpm)
  Floppy Drive: 3.5” 1.44MB Floppy Drive
  Operating System: Microsoft® Windows NT® 4.0, CD (Service Pack 5)
  Mouse: Microsoft Intellimouse® (2-button w/scroll)
  CD ROM, DVD, and Read-Write Drives: 8X/AX/32X IDE CD Read-Write

Interface Card to connect to CAISO PI System
Additional Software: MS Office Professional
Windows NT® 4.0, CD (Service Pack 5)

8 VAR Management Data Requirements Needed From CAISO

- Twelve months of 15-minute data for: system net active and reactive loads, temperature and humidity. Also include components if data is available by reliability area. This data is needed for initialization of the near real time forecast models for the VAR Management predictive mode.
- The initial SDG&E model supplied by CAISO is missing the following buses:

15021 PALOVRDE	500 kV
19220 N GILA	69 kV
20118 ROA-230	230 kV
20149 TJI-230	230 kV
21025 ELCENTRO	230 kV
24131 S ONOFRE	230 kV

An updated network model including all SDG&E buses is required.

- 24-hour schedules for load distribution factors and breakers schedules for data not available from the CAISO PI-system, and any other network data required to solve a GE-type power flow.
- Identification of ten worst outages for the initial CAISO SDG&E network.

9 CERTS Database Questions for CAISO

- How many and what data points CAISO estimates coming from the PI system for the SDG&E system?
- Will be there multiple input PI-nodes? Or, will be only one input PI-node?
- For the WSCC reduced model included in the initial network, what additional data besides SDG&E could be available from the CAISO-PI system?
- Could CAISO email CERTS a layout or list of the PI data that will be available for the VAR Management project?

10 CAISO Setup and Authorization to Work at CAISO-Alhambra

CERTS already is running the SDG&E model in the VAR prototype. CERTS is ready to start testing the application algorithm in the CAISO Alhambra environment.

APPENDIX B

REAL TIME VAR MANAGEMENT AND GRID MANAGEMENT TOOLS DESIGN OVERVIEW

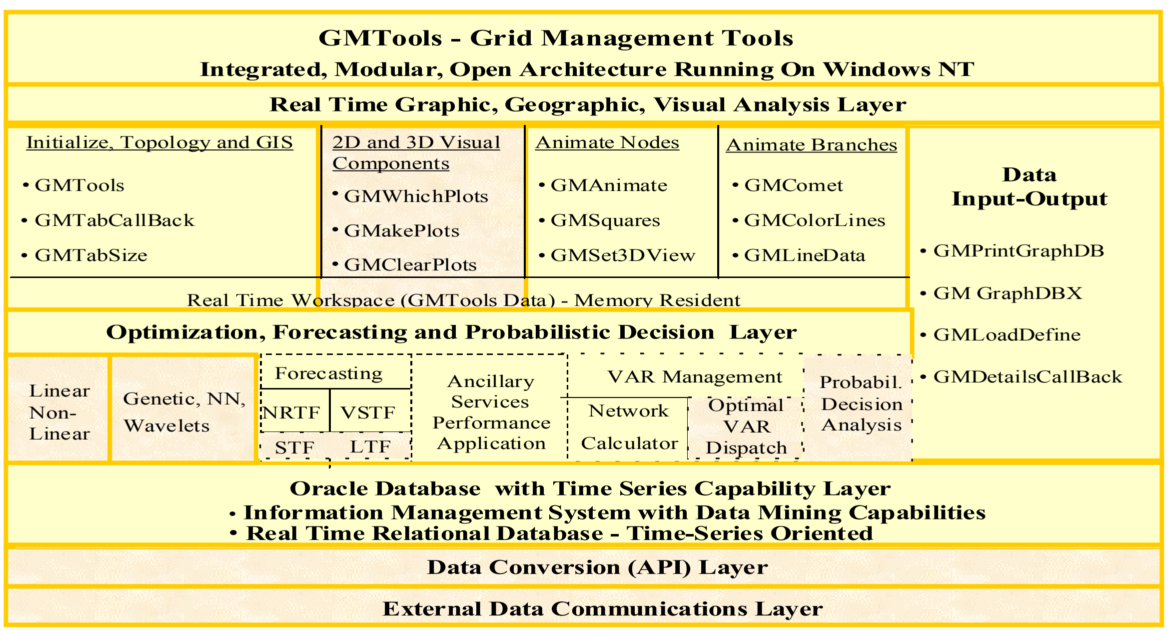
11 CERTS Grid Management Tools (GMTools)

Figure 29 is a view of CERTS Grid Management Tools (GMTools); an integrated, modular open architecture structure being used for developing and prototyping CERTS reliability adequacy applications, and the base for the CAISO VAR Management.

Figure 29 below shows the integrated modular design components of Real Time VAR Management application and its predictor with details for the routines currently available in the GMTools visualization layer.

GMTools is being specifically designed and implemented to develop end user reliability applications, training aids and visualization technology solutions. These tools will assist in the development of tools that comply with the monitoring, operational and marketing requirements originated by the deregulation and energy markets currently underway worldwide.

Figure 29 –Real Time VAR Management Application as an Integrated Component of Grid Management Tools (GMTools)



Real Time VAR Management application will utilize GMTools as its primary infrastructure for: data communications, data format conversions, real time time-series oriented database, data mining and the generic forecasting and probabilistic routines. The ASPTP prototype will also use the same GMTools infrastructure.

Real Time VAR Management application uses the GMTools visualization layer to create the hierarchical performance, tracking and prediction displays. Visualization routines are shown in the upper part (dark line) grouped in five classified blocks according to their utilization. The Visualization Toolbox Layer is a subset of routines, which interface with output data from the optimization, forecasting, probabilistic and decision analysis solvers to present past, current and near term future information for Operating Authority, Operators and Marketers on tabular, 2D and 3D graphical, geographic, concurrent and animated visualization displays.